Ministry of Defence

Human Augmentation – The Dawn of a New Paradigm

A strategic implications project



in partnership with

Bundeswehr Office for Defence Planning

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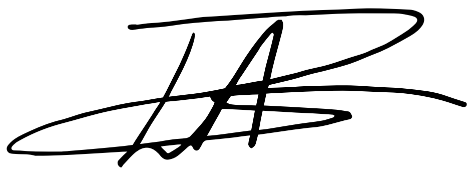
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dated May 2021



Head of Futures and Strategic Analysis

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Foreword

The prospect of using technology to radically enhance human performance has been the subject of intense debate over the last two decades. Some analysis has been pessimistic and cautionary, downplaying just how imminent such technologies are. Other commentators are more optimistic and foresee an impending technological revolution that will radically transform every aspect of our lives. What is certain is that the field of human augmentation has the potential to transform society, security and defence over the next 30 years. We must begin to understand the implications of these changes and shape them to our advantage now, before they are thrust upon us.

Technology in warfare has traditionally centred on increasingly sophisticated platforms that people move and fight from, or artefacts that they wear or wield to fight with. Advances in the life sciences and converging developments in related fields are, however, beginning to blur the line between technology and the human. Significant thought has already been given to what this means for artificial intelligence, automation and robotics, but comparatively little time has been given to what this means from a human perspective. This project seeks to address this imbalance so that we can understand the potential of human augmentation and its implications.

The project is a bilateral cooperation between Bundeswehr Office for Defence Planning in Germany and the Development, Concepts and Doctrine Centre in the UK. The output from the strategic implications project will be relevant to a wide audience across the defence and security sector. Whilst this is not a scientific publication, it draws extensively on research to provide an overview of where the key opportunities and threats are. Many technologies that have the potential to deliver strategic advantage out to 2050 already exist and further advances will undoubtedly occur. Our understanding of the technical, ethical, legal and societal implications of these technologies will be decisive in how transformative they prove to be for Defence. Our potential adversaries will not be governed by the same ethical and legal considerations that we are, and they are already developing human augmentation capabilities. Our key challenge will be establishing advantage in this field without compromising the values and freedoms that underpin our way of life.

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Contents

Preface

Aim

Scientific and technological developments related to human augmentation are beginning to accelerate and converge with other fields such as sensors, artificial intelligence, novel materials, nanotechnology and additive manufacturing. This publication is the output of a strategic implications project and offers a conceptual model for thinking about the subject, an overview of the future direction of human augmentation and related fields of study, and identifies key implications and insights for Defence.

Audience

Human Augmentation – The Dawn of a New Paradigm seeks to inform a wide audience across the defence and security sector. It will be relevant to those involved in: policy and strategy formulation; science and technology; concepts and force development; capability and acquisition; procurement; personnel and workforce planning; and operational commanders and their staffs.

Context

This strategic implications project is a bilateral cooperation between the Bundeswehr Office for Defence Planning in Germany and the UK Ministry of Defence's (MOD) Development, Concepts and Doctrine Centre, supported by the Swedish Defence Research Agency, the Finnish Defence Research Agency and the UK's Defence Science and Technology Laboratory. It is coherent with the UK's Joint Concept Note (JCN) 1/18, *Human-Machine Teaming* and JCN 1/17, *Future of Command and Control*. This project has been set in the context of the UK MOD's Defence Technology Framework, *Global Strategic Trends – The Future Starts Today* and *Future Operating Environment 2035*. It is also coherent with the German *Future Topic Human Enhancement* and its subsequent recommendations. This work has also drawn on engagement across the Defence scientific community, academia and the ongoing Multinational Capability Development Campaign's project on human performance optimisation/enhancement.

Scope

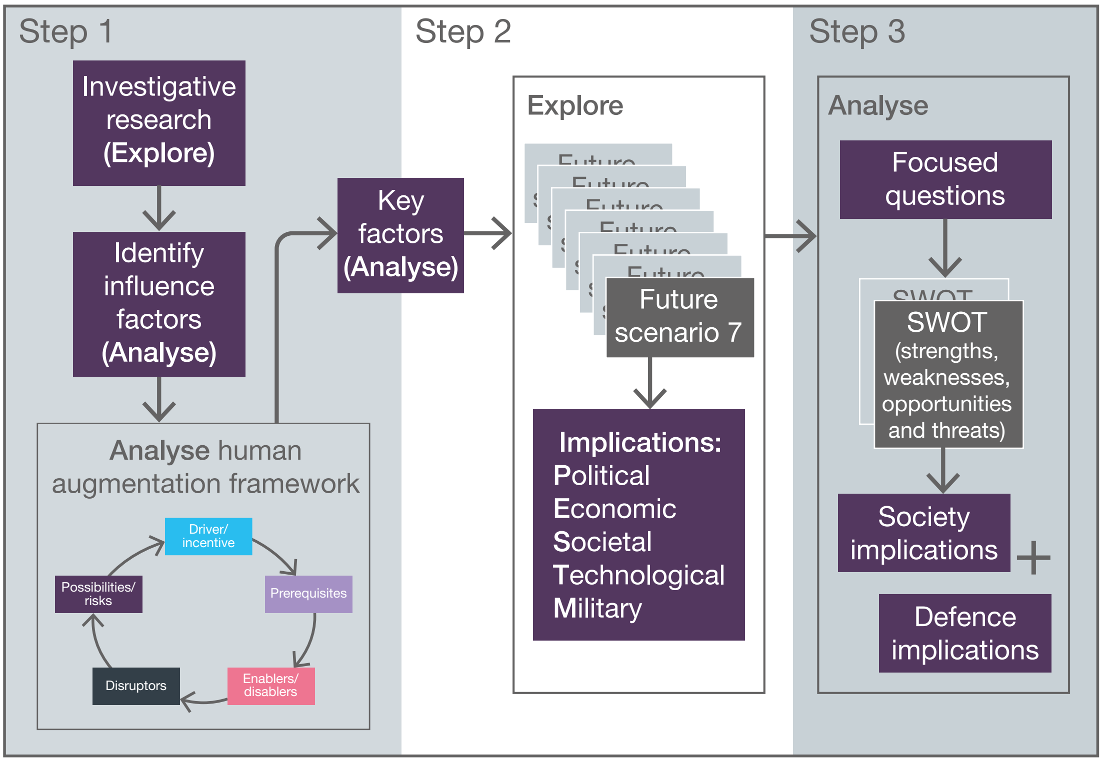
Human augmentation is a vast field with many linkages to other areas of study. There is no commonly agreed definition and it is known by many names, which are often used interchangeably. When we think of human augmentation it is easy to imagine science fiction inspired suits or wonder drugs that produce super soldiers, but we are on the cusp of realising the benefits in a range of roles now. Human augmentation will help to understand, optimise and enhance performance leading to incremental, as well as radical, improvements.

There are divergent views on how mature human augmentation technologies are and how quickly they will progress. This publication will seek to clarify this picture and identify which areas have the greatest potential for Defence. Human augmentation has

the potential to impact every facet of our lives and even change the meaning of what it means to be a human. It could challenge philosophical concepts, our belief systems, and ethical and legal frameworks in ways that we have not anticipated. This publication will cover all these issues in outline but, in the interests of the intended audience, its focus will be on the implications for society and Defence. For the purposes of this publication, human augmentation does not include leadership and excludes technologies that bestow capabilities not directly linked to existing human function (for example, flying).

Method

The project used a scenario-based approach to explore implications out to a 2050 horizon as shown in the figure below. Step one involved an initial analysis of influence factors and investigative research. From this a framework was produced to identify drivers, disruptors, risks, dependencies and key factors. Step two used these factors to construct a range of future scenarios to explore possible societal, technological, economic, political and military implications. Step three used focused questions within each scenario to conduct a series of SWOT (strengths, weaknesses, opportunities and threats) analyses, the results of which were cross-referenced to identify implications for society and Defence. Further detail on the methodology can be found at Annex A.



Project methodology

Structure

The publication is divided into six parts and two annexes.

- **Part 1 – Understanding human augmentation.** Part 1 proposes a definition for human augmentation and offers a conceptual model to understand its application. It also makes the case for why human augmentation will be increasingly important.

- **Part 2 – Human augmentation technology.** Part 2 gives an overview of the key human augmentation technologies and linked fields of study. It is not intended to be authoritative but gives a sense of what could be possible and provides a context for subsequent parts.

- **Part 3 – Ethical considerations.** Part 3 discusses the key ethical implications of human augmentation before focusing on areas pertinent to Defence.

- **Part 4 – Legal considerations.** Part 4 focuses on the key areas of law that relate to human augmentation and society, and Defence in particular.

- **Part 5 – Implications for society.** Part 5 examines societal implications to set the context for the Defence implications that follow.

- **Part 6 – Implications for Defence.** Part 6 discusses the implications of human augmentation using the Defence capability framework.

- **Annex A – Project methodology.** Annex A describes the methodology used in this project in greater detail.

- **Annex B – Technology review.** Annex B provides additional information on technologies for human augmentation.

Executive summary

Introduction

The ability to enhance one's physical, psychological or social capability has been a source of power throughout history, and warfare is the epitome of this dynamic. The paradox of war is that humans are central to its conduct but are also the weakest link. We want 'war fighters' – whether they be cyber specialists, drone pilots or infantry soldiers – to be stronger, faster, more intelligent, more resilient and more mobile to overcome the environment and the adversary. We have designed increasingly complex technologies to enhance lethality, survivability and mobility. As technology has become more sophisticated our thinking has become more focused on the machine rather than the person, but this needs to change if we are going to be effective in the future.

Recent advances in the life sciences and related technologies have led to the emergence of the interdisciplinary field known as human augmentation which has the potential to disrupt every aspect of our lives. The interdependencies and potential implications of human augmentation are so vast and complex that it is difficult to make sense of what it means for the future of society and Defence. The aim of this strategic implications project is to take the first step in making sense of these potential changes to human capabilities. It offers a conceptual model for thinking about human augmentation, its future direction and identifies key implications for Defence and its stakeholders.

Key observations

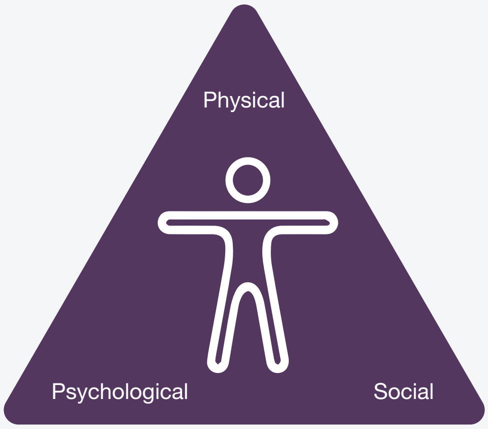
Human augmentation will become increasingly relevant, partly because it can directly enhance human capability and behaviour and partly because it is the binding agent between people and machines. Future wars will be won, not by those with the most advanced technology, but by those who can most effectively integrate the unique capabilities of both people and machines. The importance of human-machine teaming is widely acknowledged but it has been viewed from a techno-centric perspective. Human augmentation is the missing part of this puzzle.

Thinking of the person as a platform and understanding our people at an individual level is fundamental to successful human augmentation. Industrial Age warfare saw people as interchangeable components of military units or the material with which to operate the platforms – vehicles, aircraft and ships. These platforms are routinely monitored and analysed but it is remarkable that our ability to understand our most critical capability – the human – is so under-researched. Successful application of human augmentation demands a more sophisticated approach to understanding our people and their capabilities. Defining the key elements of the 'human platform' – physical, psychological and social – provides a conceptual baseline to enable a multidisciplinary conversation.

Conceptualising the human as a platform

Physical performance is the capability to affect the physical environment and move within it. Strength, dexterity, speed and endurance are key components and there is often a trade-off between them.

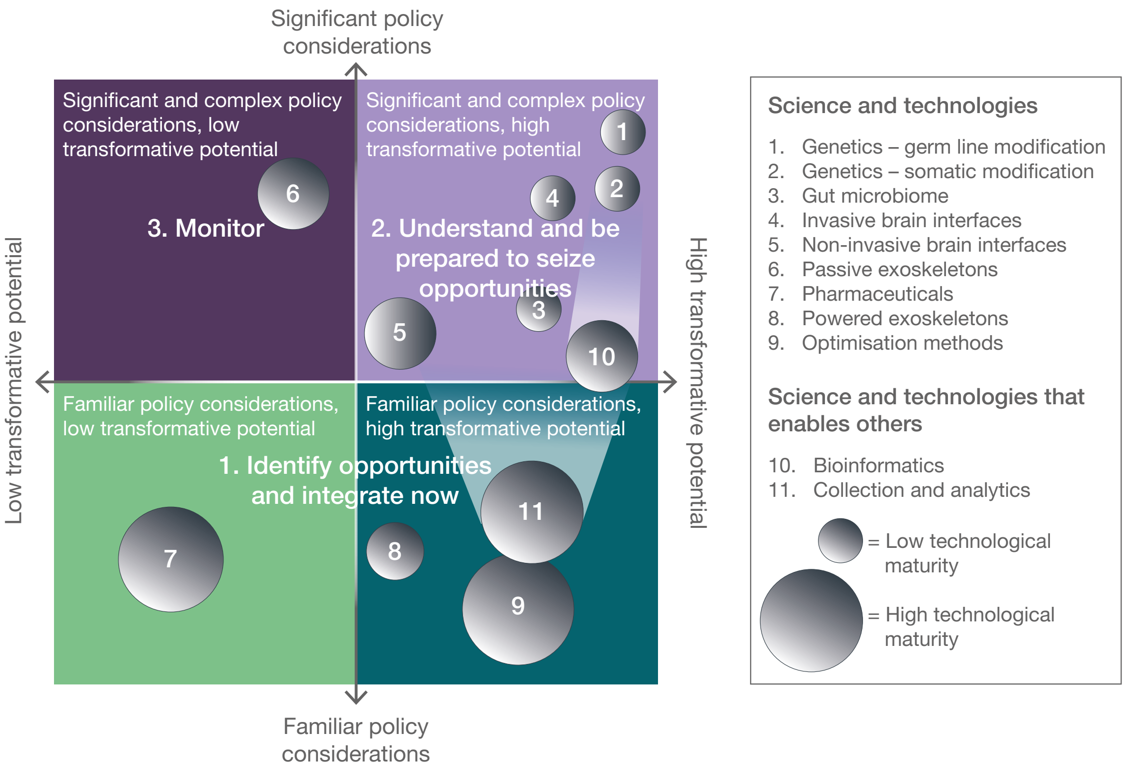
Psychological performance comprises cognition, emotion and motivation. Cognition is the mental action or process of acquiring knowledge and understanding through thought, experience and the senses. It includes processes such as attention, the formation of knowledge, long-term and working memory, reasoning, problem solving and decision-making. Emotion describes the subjective human experience and is closely linked with motivation, which is the force that energises, activates and directs behaviour.



Social performance is the ability to perceive oneself as part of a group and the readiness to act as part of the team. It is founded on self-awareness and the ability to understand the behaviour of others. It is tightly linked to communication skills, collaboration and trust. The core tenet of social performance is group cohesion.

Human augmentation is not a shortcut – getting the basics of human physiology, biochemistry and psychology right is a prerequisite to human augmentation and will become more important in the future. Research into human augmentation has shone a stark light on how little we know about how to do the basics well. We need to do more to understand the precise effects of nutrition, sleep and hydration, and their relationship with other areas of the body to realise significant, yet untapped potential. Technology that improves monitoring will make it possible to individually optimise sleep, nutrition and other factors to deliver transformational gains across an organisation at relatively low cost and limited ethical risk.

Human augmentation is not just tomorrow's business, there are short-term and long-term opportunities that require engagement today. The following matrix illustrates the technical maturity and the magnitude of policy considerations of human augmentation technologies. It shows that there are technologies that could be integrated today with manageable policy considerations. The most transformative technologies (for example, genetics and brain interfaces) currently sit at a low level of technological maturity but we must be prepared for this to change quickly. Bioinformatics and collection and analytics (encompassing sensors, artificial intelligence-enabled processing) are particularly important enablers for other human augmentation technologies and warrant focused research and development attention.



Feasibility assessment

We cannot wait for the ethics of human augmentation to be decided for us, we must be part of the conversation now. The ethical implications are significant but not insurmountable; early and regular engagement will be essential to remain at the forefront of this field. Ethical perspectives on human augmentation will change and this could happen quickly. There may be a moral obligation to augment people, particularly in cases where it promotes well-being or protects us from novel threats. It could be argued that treatments involving novel vaccination processes and gene and cell therapies are examples of human augmentation already in the pipeline.

The need to use human augmentation may ultimately be dictated by national interest. Countries may need to develop and use human augmentation or risk surrendering influence, prosperity and security to those who will. National regulations dictating the pace and scope of scientific research reflect societal views, particularly in democracies that are more sensitive to public opinion. The future of human augmentation should not, however, be decided by ethicists or public opinion, although both will be important voices; rather, governments will need to develop a clear policy position that maximises the use of human augmentation in support of prosperity, safety and security, without undermining our values.

Governance in Western liberal societies and international institutions is already unable to keep pace with technological change and adoption of human augmentation will exacerbate this trend. National and international governance will be challenged by the myriad of implications of adopting human augmentation technologies. This could lead to a new arms race and inter- and intra-state tensions if not carefully managed through early and regular dialogue.

Economic forces will have a strong influence on human augmentation development and they may not be in the best interests of society. The private sector can employ more resources and have greater organisational agility than state institutions, meaning that they will remain at the cutting edge of human augmentation research. Enhancements will be highly profitable, and companies are likely to focus on human augmentation that is lucrative, rather than that which is of most benefit to humanity. The tension between states, societies and market forces is nothing new, but the consequences of mismanagement could be more severe in the case of powerful human augmentation technologies.

The reliance on personal data to enable human augmentation will pose significant data security and privacy challenges. The frameworks to secure this data will have to be both national and international in nature, ensuring that it is easily shared and used for common good, but also well protected.

Human augmentation is our first insight of what lies beyond today's Information Age – the coming of the Biotech age. The Biotech age will see focus on the human grow. No longer will it be adequate to regard people merely as the means to operate the machine. The interdisciplinary nature of human augmentation will render our current Industrial Age model of Defence ineffective. Defence must consider how it reorganises to meet a future that will demand a human-centric approach to warfare where the person is armed with the capabilities to integrate fully into a single platform.

Human augmentation is bringing about a securitisation of the life sciences. Defence will need to develop a more effective relationship with those who work in the life sciences as the dual-use nature of emerging human augmentation technologies becomes clear. Governments will need to work with the scientific community to establish a framework that safeguards and supports national security whilst supporting collaboration.

Differences in national, cultural and legal approaches will lead to an uneven uptake of human augmentation within international alliances. This will further complicate interoperability, integration and deconfliction. Overcoming these challenges will demand closer cooperation between allies. Alliances must therefore start work now to understand how and where to prepare for the use of human augmentation.

Human augmentation threats. Cultural and ethical considerations will inform the extent to which opportunities are seized, but human augmentation threats will be forced upon us irrespective of our own normative standpoint. We must understand and address such threats or otherwise risk creating a strategic vulnerability. Threats will emanate from states, terrorist groups, criminals, lone actors, or even malpractice in legitimate activities. Protecting ourselves will demand a level of scientific, ethical and legal proficiency that outmatches the adversary. Mitigations may not involve human augmentation technology itself but understanding the field and developing comprehensive policies and capabilities to protect society and individuals will be critical.

Human augmentation may lead to fundamentally new concepts of warfare. In the next 30 years, increasing use of autonomous and unmanned systems – from the tactical to strategic level – could significantly increase the combat effect that an individual can bring to bear, but to realise this potential the interfaces between people and machines will need to be significantly enhanced. Human augmentation will play an important part in enabling this interface and, if done effectively, it will significantly alter our force structure, equipment programme and doctrine. It is important to realise that the more human augmentation is embedded into Defence planning and practice, the more likely it is to become a target itself for an adversary; thus, counter-human augmentation measures need to be considered in parallel with the adoption of human augmentation.

Human augmentation will play a key role in reducing the risk of cognitive overload as warfare becomes faster, more complex and more congested. Bioinformatics are likely to play a key role in identifying commanders and staff with the right cognitive and adaptive potential for command and control roles. Brain interfaces linked to machine learning algorithms have the potential to rapidly accelerate the speed and quality of decision-making.

Today's rehabilitation tools: tomorrow's enhancements – physical and mental rehabilitation may, in the near term, prove to be the front line of human augmentation in Defence. Advanced prosthetics to rehabilitate wounded personnel represent the cutting edge of robotics and the latest neurostimulation devices and pharmaceuticals have been used to treat post-traumatic stress disorder. Further development of these treatments will not only help to rehabilitate injured personnel, but they could also pave the way for future enhancements.

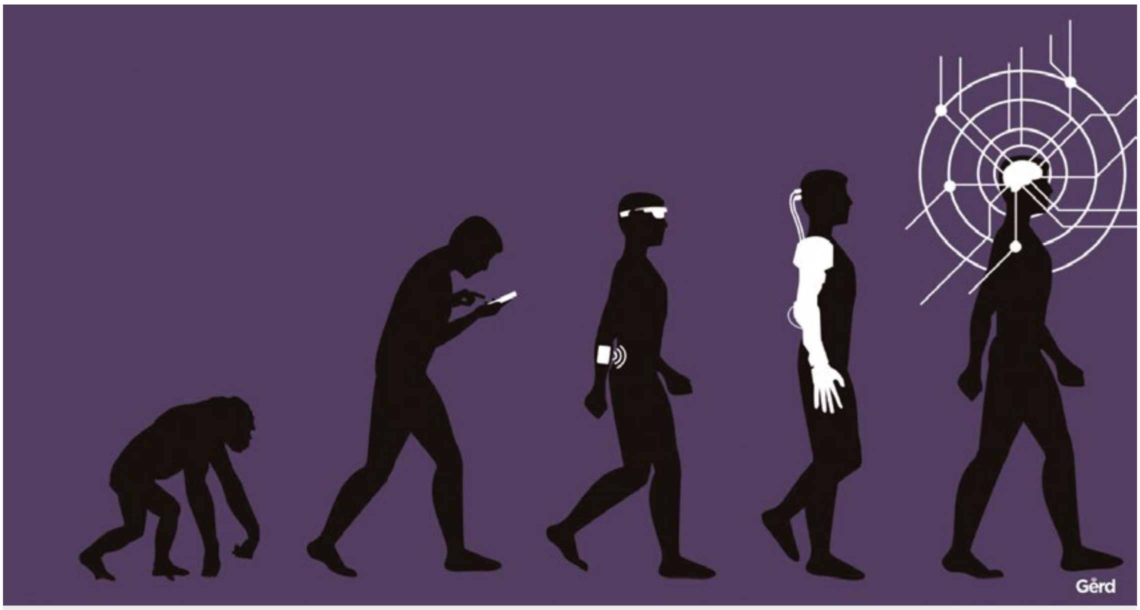

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Part 1

Understanding human augmentation

In its broadest sense, human augmentation has been practiced since the dawn of humankind. Humans have adorned themselves with decorative garments to increase their social standing, or concocted substances to boost their physical performance or alter their emotional state. They have fashioned weapons to increase their prowess in combat and armour to protect themselves.

The ability to enhance one's physical, psychological or social capability and resilience has been a source of influence and power throughout history. The paradox of war is that people are central to it, but they are also its weakest link. We want 'war fighters' – whether they be cyber specialists, drone pilots or infantry soldiers – to be stronger, faster, more intelligent, more resilient and mobile to overcome the environment and the adversary. We have therefore designed technologies to enhance lethality, survivability and mobility. As technology has become more sophisticated, our scientists have focused on machines rather than people, but this is beginning to change. Recent advances in the life sciences have led to the emergence of the interdisciplinary field known as human augmentation, which has the potential to disrupt every aspect of our lives.



Six million years of evolution to where we are today and now we have the tools in our hands to decide how our continued evolution should be shaped

Section 1 – Definitions

There are numerous and varied definitions surrounding human augmentation and most focus on the concept of performance enhancement. Human augmentation includes chemical, physical and biological augmentation and the modification of the human but, it is not exclusively about adding 'things' to the human, it also includes applying scientific insight to areas such as sleep management and personalised nutrition to improve performance. This publication proposes a definition for human augmentation as: the application of science and technologies to temporarily or permanently improve human performance. This field can be further divided into human performance optimisation and human performance enhancement. Human performance optimisation is the use of science and technologies that improve human performance up to the limit of biological potential without adding new capabilities. Human performance enhancement is the use of science and technologies to enhance human performance **beyond** the limit of biological potential and can include additional capabilities beyond those innate to humans (for example, night vision).

Figure 1 illustrates that the delineation between human performance optimisation and human performance enhancement is outcome-based. It is agnostic of technological sophistication and whether the effects are temporary or permanent, invasive or non-invasive. For example, binoculars have been around for nearly 200 years and passive night vision devices for nearly 60 years – both are commonplace technologies, but offer significant, albeit temporary, sight enhancement. Equally, laser eye surgery is only 35 years old, more sophisticated and permanent, but in most cases only optimises sight up to the individual's biological potential. Permanence and degree of invasiveness are also important aspects of human augmentation and will be discussed later in this publication. Noting that night vision goggles and binoculars are technically included in the definition of human augmentation, this paper will focus mainly on the implications of novel science and technology that are more closely integrated with the human body.

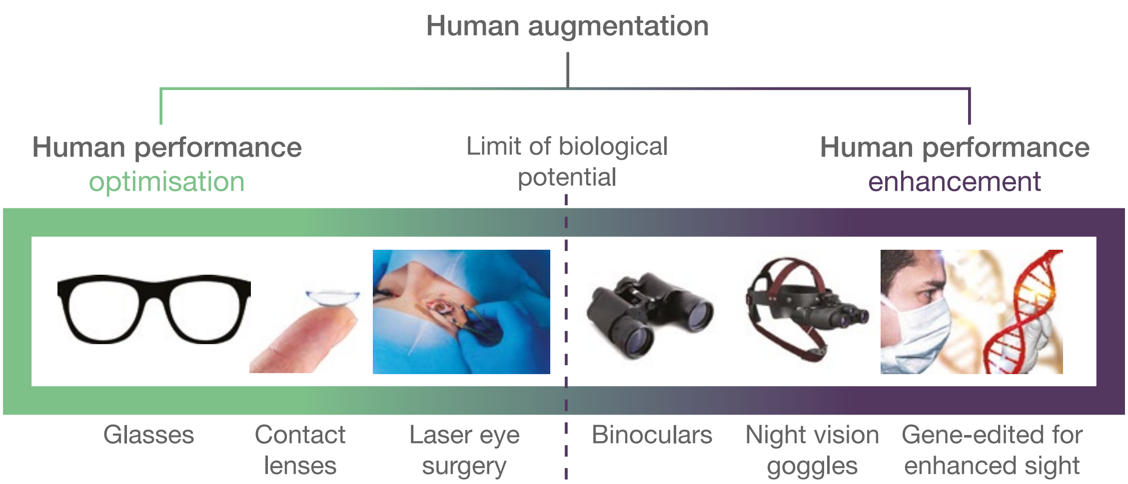


Figure 1 – Human augmentation definitions

Human augmentation is relevant across society and Defence. People are constantly affected by internal factors (for example, ageing, hydration or disability) and external factors (for example, weather, pollution or disease) that lead to fluctuations in performance that can be fleeting or enduring. The effect of human augmentation can therefore vary at any given time as outlined in Figure 2. For example, the same brain computer interface could be used to mitigate the effects of a stroke, help to optimise a layman to perform a specific function, or enhance a specialist who needs to be even better. Human augmentation is therefore relevant across society and across Defence; it can mitigate shortfalls, optimise existing performance and extend performance beyond biological limits.

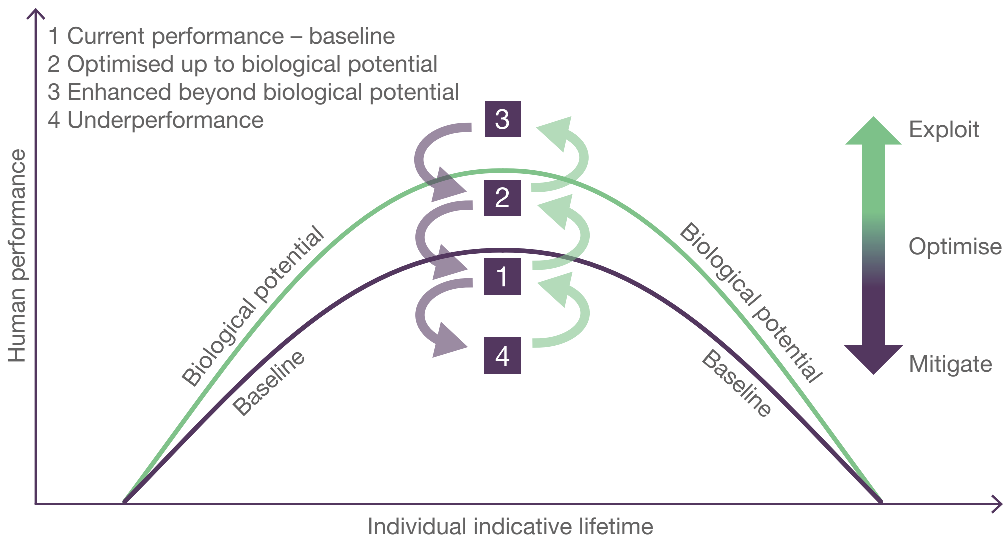


Figure 2 – Human augmentation and the fluctuation of human performance

Section 2 – The human platform

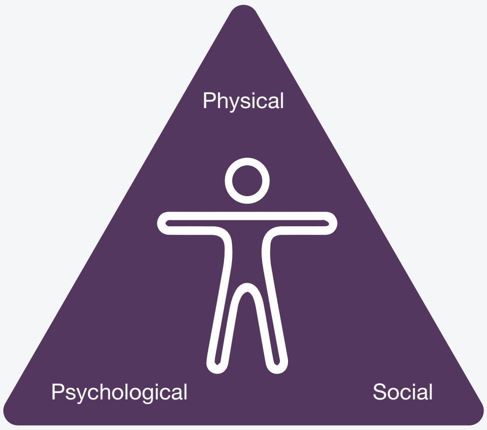
> The *Integrated Operating Concept* places a premium on operating, it also places a premium on adaptability – the ability to adapt to war fight. And this in turn emphasises the importance of our people – who have always been our adaptive edge.
>
> Chief of the Defence Staff,
> launching the *Integrated Operating Concept*, September 2020

Conceptualising the human as a platform is fundamental to thinking about human augmentation and this project offers a model to do this. The performance of traditional military platforms – vehicles, aircraft and ships – is routinely monitored and analysed but it is remarkable that our ability to understand our most critical capability – people – is so under-researched. Central to the approach of this project is the idea that each person must be understood at the individual level. Successful application of human augmentation demands a more sophisticated approach to understanding our people and a way of achieving this is to define the key elements that collectively represent the human platform; these are physical, psychological and social in nature. It is recognised that it is impossible to neatly separate the human into three distinct areas and that this model is a conscious oversimplification.

Conceptualising the human as a platform

Physical performance is the capability to affect the physical environment and move within it. Strength, dexterity, speed and endurance are key components and there is often a trade-off between them.

Psychological performance comprises cognition, emotion and motivation. Cognition is the mental action or process of acquiring knowledge and understanding through thought, experience and the senses. It includes processes such as attention, the formation of knowledge, long-term and working memory, reasoning, problem solving and decision-making. Emotion describes the subjective human experience and is closely linked with motivation, which is the force that energises, activates and directs behaviour.



Social performance is the ability to perceive oneself as part of a group and the readiness to act as part of the team. It is founded on self-awareness and the ability to understand the behaviour of others. It is tightly linked to communication skills, collaboration and trust. The core tenet of social performance is group cohesion.

Section 3 – Technology and future warfare

> Whilst it is envisaged that humans will continue to be central to the decision-making process, conflicts fought increasingly by robots or autonomous systems could change the very nature of warfare.
>
> *Global Strategic Trends – The Future Starts Today*

Advances in artificial intelligence, robotics and autonomy mean that human processing power, speed of action and endurance are being rapidly outpaced by machines. Technology is already chipping away at people's role in war and many militaries have come to rely on it. It remains to be seen whether the Information Age will really change the nature of war, but the role of people is being challenged in three key areas: data, complexity and speed.

a. Technology has exponentially increased the amount of data in the world, and the amount available to commanders. People lack the bandwidth to effectively process large amounts of data, which thickens the 'fog of war' and increases the risk of information overload. Thus, data has to be secure, tamper-free and trustworthy, otherwise not only is it useless, it could be very dangerous if its veracity has not been checked.

b. The emergence of new domains and the deepening interconnectedness between them has increased the complexity of war. The information environment

has also been supercharged by the pervasiveness of mass media, sensors, data and global communications. This has led to tactical events having almost immediate strategic consequences and vice versa.

c. The speed of war is increasingly beyond that in which humans can observe, orientate, decide and act. In physical terms, hypersonics and space-based capabilities will see missiles fly near the Earth at a mile per second; too fast for humans to make crucial decisions on their own.[1] In conceptual terms, cyber and information operations are fought at the velocity of fibre optics.

Section 4 – Humans and future warfare

> As long as humans have an advantage in the areas of creativity and judgment, we will have a major role at the frontlines. … when missions have a significant degree of uncertainty, require the ability to adapt on the fly, and have the chance for major reversals, the adaptability of humans is invaluable.[2]

Technology offers significant advantages, but there are many instances throughout history where people, not machines, have proven to be decisive. Perhaps the most profound example of the value of contextualised human judgement is Stanislav Petrov's actions in 1983 where he averted a nuclear war by overriding a Soviet automated early warning system that had incorrectly identified a United States missile attack.[3] Today, the risk of over-relying on technology has perhaps never been greater because its pervasiveness has conditioned us to rely on algorithmic judgements in so many aspects of our daily lives. We must remind ourselves that people have, at least for now, the edge over machines, and will continue to have a role in future war for three key reasons.

a. War is, by its nature, a human endeavour. So far, technology has not changed the nature of war, but it has changed its character. People will still be central to war but the way in which they play this role will change. This may mean less combat troops and more cyber specialists, drone operators and computer technicians in the future, but the stress and threat to life will likely remain, albeit manifested in different ways. Warfare is likely to be more 'remote' and psycho-cyber intensive, but the aftermath will still require 'boots on the ground'.

b. Humans remain unrivalled (for now) in their general intelligence. When the unforeseen happens, people will be required to step in to fulfil the mission, avert crises or seize unforeseen opportunities.

c. Technology will become increasingly capable, but society will influence the pace and extent of its adoption. Bravery, skill and honour have been ingrained into our societies for centuries and this will not change overnight. Outsourcing war to machines so that blood is not spilt might reduce the human cost of conflict, but inadvertently increase its likelihood.

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1 Fryer-Biggs, Z., The Atlantic.com, (2019), 'Coming Soon to a Batlefield: Robots That Can Kill'.

2 Herr, A., National Defense University Press, (2015), 'Will Humans Matter in the Wars of 2030?'.

3 See Stanislav Petrov's obituary in the New York Times for a more detailed account.

Section 5 – The case for human augmentation

People are Defence's most valuable asset but also a key vulnerability; people get hungry, tired, scared and confused. Machines on the other hand are incapable of these things but have weaknesses of their own. The winners of future wars will not be those with the most advanced technology, but those who can most effectively integrate the capabilities of people and machines at the appropriate time, place and location. The growing importance of human-machine teaming is widely acknowledged but this has been discussed largely from a techno-centric perspective. Human augmentation represents the missing part of the puzzle and will become increasingly important over the next 30 years because of three key drivers of change.

- Accelerating progress in science and technology means we **can** do more.
- There are opportunities and threats that mean we **should** do more.
- Changes in society mean we **want** to do more.

Can do more. There is a growing sense that we are moving towards a frontier of unprecedented opportunity to improve humanity, which means we can do more. The fields of biomedicine, neuroscience, synthetic biology, computation, material technology, biomechatronics and social sciences have developed at pace to make possible what used to be the preserve of science fiction. Notwithstanding significant ethical and legal challenges, the science behind these technologies has been proven and cannot be undone. The origin of many augmentation ideas of applications lies in the health care sector. Large technology and pharmaceutical corporations see the economic opportunity in human augmentation and are investing heavily in these technologies and rich elites are also investing huge sums to develop life extension technologies. These efforts will drive human augmentation development, making it more accessible. The key question is how societies will embrace it and adopt it and for what purpose.

Should do more. The therapeutic benefits of human augmentation could help us to lead happier, longer and healthier lives, free from chronic illness and heritable disease. It could protect us against pandemics, or at least provide us with the tools to react more effectively to them. Brain interfaces mixed with augmented and virtual reality could dramatically enhance our experiences and our ability to express ourselves. New concepts of intelligence and higher levels of creativity could emerge by connecting brains with other brains and/or computers. The benefits of human augmentation are so profound that they could be considered the stuff of fantasy, but perhaps no more so than the proposition of landing on the moon might have seemed in 1950. There are risks inherent in human augmentation. The COVID-19 pandemic has exposed our vulnerability to pandemics, and unchecked use of human augmentation could be used to increase the risk and severity of them. Threats could emanate from states, terrorist groups, criminals, lone actors or even malpractice in otherwise legitimate activities. Protecting ourselves may not directly require human augmentation but understanding the underlying technology and developing comprehensive policies and capabilities will be critical.

Want to do more. Happiness, well-being and longevity are moving up the human agenda. There is also a growing realisation that wealth and productivity – the standard metrics of individual and societal success – do not necessarily equate to happiness or fulfilment. While most people still want to be wealthy and have good jobs, they also want

to be fitter, healthier and more attractive. Human augmentation will be seen as a means of fulfilling these desires.

Diffusion of advanced knowledge. The diffusion of advanced knowledge of the human body will be a key driver for human augmentation. Social media and algorithms designed to push information to interested people is leading to specialist information being readily available. Although bogus information is spread, in the vast majority of cases societies are much better informed about how the human body works and how to look after it. Social media is also fuelling people's desire to be fitter and healthier and this will increase demand for human augmentation in the future. Increasing body awareness, particularly among young adults, indicates a generational change in attitudes toward health. The use of technology in professional sports has also increased significantly over the last 30 years and, as it becomes less expensive, is cascading into recreational sport and everyday life.[4] This is putting personalised biometric information into the hands of millions of people and enabling them to track and improve their performance.

Key deductions and insights

- People have sought to augment themselves since the dawn of humanity – but over the next 30 years our ability to manipulate the human body will radically improve.

- Human augmentation encompasses science and technologies that optimise or enhance human performance.

- There are many different definitions of human augmentation. Finding consensus and an agreed approach to human augmentation will be essential in allowing different disciplines to collaborate effectively and realise its benefits.

- We need to adopt a human-centric approach to realise the opportunities of human augmentation. Thinking of the human as a platform – with physical, psychological and social aspects – will be central to this.

- Increasing data, complexity and speed is challenging the role of people in war but will not replace them: war is a human endeavour; people have skills that are still unrivalled by machines; and cultural and societal norms will take time to accommodate the role of machines.

- Human augmentation is inevitable because: we have already developed technologies and there is no going back; there are threats and opportunities that we should address; and there is a growing demand from society.

4 Professional sport has used Global Positioning System (GPS) tracking to monitor performance, prevent injury and even develop new tactics for nearly 15 years and similar wearable technology is now widespread in society.



Part 2

Human augmentation technologies

Understanding the human body is the critical foundation of human augmentation. The most sophisticated augmentation is not, necessarily, the most effective – getting the basics right could produce transformative results. This part provides an overview of emerging human augmentation technologies most pertinent to society and Defence. It will conclude with potential employment considerations and an assessment of the feasibility of the technologies. Further information about the human augmentation technologies and their application can be found at Annex B.

Section 1 – Understanding the human body

The human body is incredibly sophisticated and understanding how it works is fundamental to successful augmentation. Our brains are more complex than any other known structure in the universe. Human bodies are complex ecosystems hosting ten times more bacteria cells than cells of their own. People are unique: each person smells different, walks differently, hears differently and responds to medication differently. Understanding how the body works is a monumental undertaking but recent scientific and technological developments mean that, increasingly, we can unlock the secrets within the $3x10^{14}$ cells in a human body.

Side effects and unintended outcomes. The relationship between augmentation inputs and outputs is not as simple as it might appear. An augmentation might be used to enhance a person's endurance but could unintentionally harm their ability to think clearly and decisively in a timely fashion. In a warfighting context, an augmentation could make a commander more intelligent, but less able to lead due to their reduced ability to socially interact or because they increasingly make unethical decisions. Even a relatively uncontentious enhancement such as an exoskeleton may improve physical performance for specific tasks, but inadvertently result in a loss of balance or reduced coordination when not being worn. The notion of enhancement is clouded further by the intricacies of the human nervous system where a modifier in one area could have an unintended effect elsewhere. Variation between people makes designing enhancements even more challenging.

Understanding. The answer to the conundrum of unintended outcomes is to invest as much effort in understanding the human body as we do in optimisation or enhancement. We therefore augment not only to improve human performance, but also to understand it. As our understanding of the human body improves, so too does our ability to optimise performance without resorting to invasive, permanent or controversial technologies. Collecting and analysing data on human performance can identify aspects of individual behaviour (for example, diet, sleep and activity) that can be adjusted to deliver

performance gains equal to or better than drugs or surgery. This is where understanding human genomics and epigenomics at the individual level is absolutely essential – it is not 'one size fits all' and is not dissimilar from the concept of 'personalised medicine'; in other words the right drug, at the right dose, to the right person at the right time.

Collection and analytics. Devices that track movement, heart rate, oxygenation levels and location are already commonplace and will become increasingly accurate and sophisticated, making it possible to gather an increasingly wide array of performance data in real time. We can also analyse data in ways that were impossible even five years ago. Artificial intelligence can analyse massive sets of information almost instantaneously and turn it into products that can inform decision-making. This marriage of data collection and analytics is the foundation of future human augmentation.

Section 2 – Optimisation methods

Getting the basics right

High-end augmentation will be important, but getting the basics right can, in many cases, deliver significant improvements for less cost and at lower risk. Using high-end human augmentation technologies to mitigate avoidable performance shortfalls is a poor use of resource and could undermine motivation and professionalism. The precise effects of nutrition, sleep and hydration, and their relationship with one another, is not well documented but we know there is untapped potential. One example is the link between physical exercise and improved cognition; this phenomenon has been known for some time, but it has only recently been possible to precisely understand the science behind it. Improved monitoring technology will make it possible to tailor the benefits of nutrition, sleep and other fundamentals to each person, leading to significant improvements to an organisation at low cost and limited ethical risk. While we are only just beginning to understand how improved monitoring could increase performance there appears to be significant potential. Illustrative optimisation methods are shown in Figure 3.

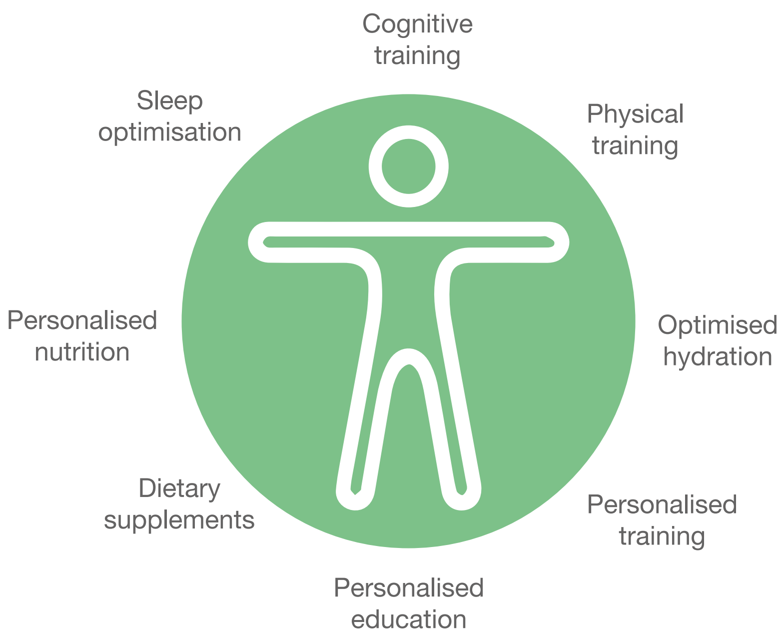


Figure 3 – Illustrative optimisation methods

The future of wearables

Current or emerging technology in this field includes: increasingly accurate heart rate monitoring; earrings that measure body temperature and pulse; shoes that generate their own power to sense bodyweight and movement; contact lenses that analyse tears to predict your emotional state and project information; clothes that sense your physiology and give you small directional taps on your shoulders to provide screen-free Global Positioning System (GPS); and 'smart buttons' in clothes that collectively understand your habits and inform other linked technologies – from car to coffee machine – to optimise your life. Wearables to monitor chronic health conditions such as diabetes are a notable growth area and may even develop towards closed-loop systems that measure and treat symptoms in the future.



Sleep

Increasingly sophisticated ways of studying the brain while we sleep is producing a wealth of data that we are only just beginning to understand.[5] The benefits of adopting good sleeping patterns will deliver huge benefits to both individuals and society. Nearly every aspect of our daily lives such as mental and physical health, public safety and productivity would improve, yet so many individual and organisational approaches fail to recognise this. In a military context sleep optimisation is difficult to employ but important to get right since it directly affects physical ability and resilience as well as attention and decision-making.

Personalised nutrition

Improved understanding of our genetics and general health could make precision nutrition a realistic possibility. Diets designed around an individual's biology have been proven to help prevent disease and improve physical and psychological performance.[6] As an example, the trillions of bacteria, viruses and fungi that live in our gut – collectively known

5 Walker, M., (2017), *Why We Sleep: The New Science of Sleep and Dreams*.

6 Personalised nutrition partially overlaps with related terms such as precision nutrition, nutrigenomics, nutrigenetics and nutritional genomics. Ordovas, J. M., et al., *The British Medical Journal*, (2018), 'Personalised nutrition and health'.

as the gut microbiome – differ in all of us and understanding foods that best interact with them can yield significant benefits. This science is only 15 years old and further research is required, but it has already shown how individuals respond differently to the same diet.[7]

An estimated half of adults in the UK take supplements on a regular basis.[8] This market is expected to grow to over £12 billion by 2023.[9] This trend is being replicated in other developed countries.[10] Categories include sports nutrition, weight management, vitamins and dietary supplements. The market is, however, fuelled by misinformation and regulatory challenges, not to mention varying rates of effectiveness of the products. For example, while creatine has been proven to increase power output and endurance, results vary; to be effective its use must be tailored to the individual.[11]

Section 3 – Core human augmentation technologies

Figure 4 provides an overview of how human augmentation technologies apply to each function and identifies four 'core human augmentation technologies' – genetic engineering, bioinformatics, brain interfaces and pharmaceuticals – that could improve psychological, physical and social performance.

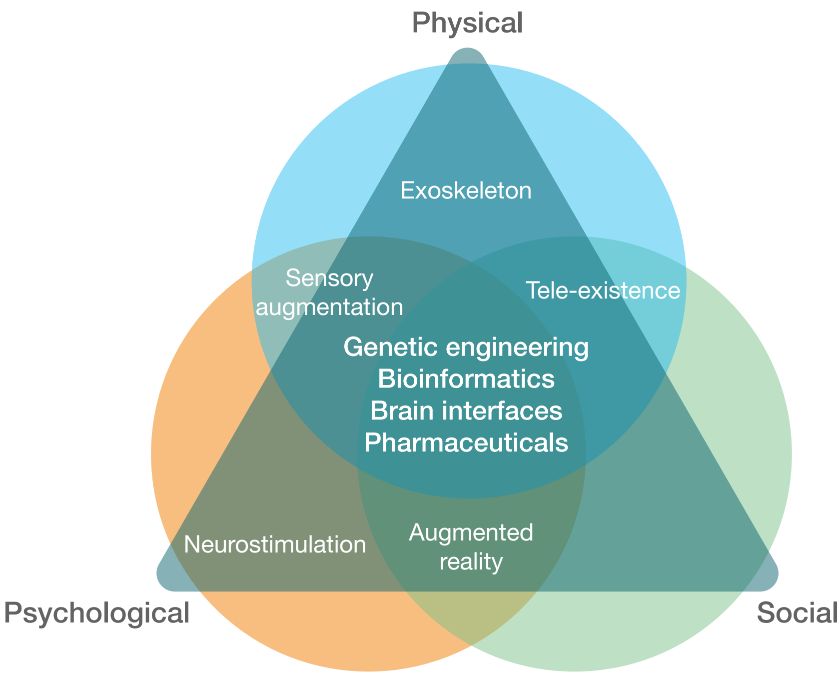


Figure 4 – Human augmentation technologies and the human platform

7 Defence Science and Technology Laboratory report number DSTL/CR119817.

8 Community Research, (2018), *Food Supplements Consumer Research.*

9 Casey, A., et al., (2014), *British Journal of Nutrition*, 'Supplement use by UK-based British Army soldiers in training'.

10 For details of the Food Supplements Working Group (AK NEM) within Food Federation Germany see https://www.lebensmittelverband.de/en/federation/organization/food-supplements-working-group-ak-nem

11 Buford, T. W., et al., (2007), *Journal of the International Society of Sports Nutrition*, 'International Society of Sports Nutrition position stand: creatine supplementation and exercise'.

Genetic engineering

Genetic engineering refers to modification of reproductive cells (germline engineering), or cells in the grown organism (somatic modification). Germline modification affects all cells in the organism and the change is passed on to the next generation. Somatic modification affects only the target cells and those cells descended from them in the body, hence is limited to the individual being treated. Genetic engineering has been around for some time but has so far been limited to relatively crude and simple modifications, often involving just one or two genes.

Creating genetically modified humans has been widely considered unacceptable for many years and is formally prohibited in over 40 countries, but there are signs that this stance is being challenged by the advent of new technologies. For example, the development in 2012 of a technique called clustered regularly interspaced short palindromic repeats (CRISPR) provides a set of 'molecular scissors' that are cheaper, faster and more accurate than previous methods of genetic editing. In 2019, CRISPR was used to treat a blood disorder in the first somatic modification of a person. The year 2020 will see further trials to restore sight in patients suffering from an inherited eye disorder. This and other recent developments are beginning to offer significant potential for a number of reasons.

a. **Greater range.** Gene editing can now add, delete or alter specific elements of DNA in the target genome. CRISPR can create multiple changes at once.

b. **Increased specificity and integration.** Specific regions of DNA can be targeted by cutting tools so that changes are more precise and safer. There are still off-target effects but newer techniques such as prime editing are improving the targeting process.

c. **Improved duration of effect.** Being able to target the genome rather than simply depositing DNA into cells means that edits are reproduced as the cell divides and the effect is promulgated.

d. **Easier production.** New production techniques are often easier, cheaper and faster to develop and perform.[12]

Future opportunities. Genetic engineering could be used to prevent people from inheriting incurable diseases or traits that make them more susceptible to cancer and dementia. It also represents the first step away from generalised medicine, where people are treated based on population averages, to precision medicine based on an individual's personal biology. Combining genetic engineering with artificial intelligence is likely to lead to radical improvements in medicine. However, genome editing as a means to deploy human augmentation bears risks and vulnerabilities since such changes could be targeted by 'genetic' weapons.

Future challenges. Genetic engineering is still at an early stage of development and is only just moving from the laboratory to human trials. Numerous challenges remain, not least the need to develop new vehicles to carry the genetic code and better understand the unintended side effects. The most significant challenges, however, are ethical and social in nature. These will be covered in Parts 3 and 5 respectively.

12 University of Cambridge, PHG Foundation, 'Somatic genome editing: an overview'.

CRISPR controversy



The most controversial use of CRISPR was in November 2018 when Chinese scientists, led by He Jiankui, used it for germline modification in human embryos to make them less susceptible to HIV. The procedure has still not been independently verified but it nevertheless shocked the global scientific community amid concerns that the technology was too premature for use on humans, and that it needlessly risked the long-term health of the three consequent babies and their offspring. As a result of the experiment, He Jiankui was jailed for three years for 'illegal medical practice' and the scientific community moved to establish a moratorium on further work in this area. Of note, Jiankui's technique involved disabling a gene for a protein called CCR5 which, when deleted from mice in a separate study, was found to improve their cognitive abilities. This has led some to speculate that CRISPR may already have been used, possibly inadvertently, to enhance human traits.

Bioinformatics

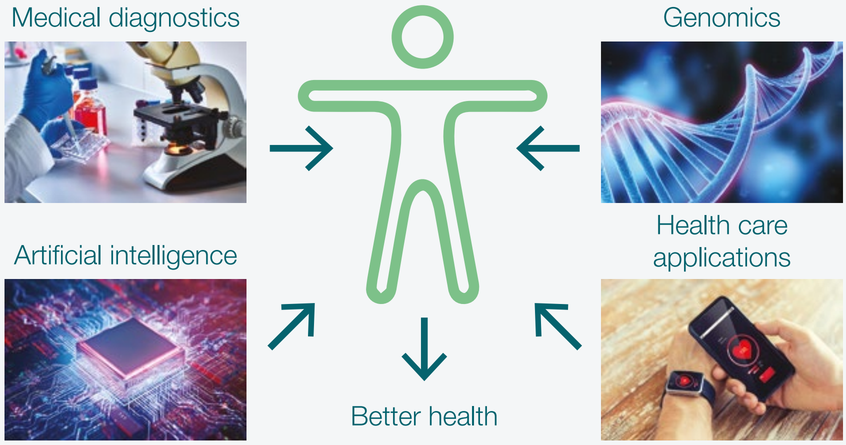
Bioinformatics is an interdisciplinary field that applies computation and analysis tools to capture and interpret large sets of biological data.[13] It is closely linked to collection and analytics but takes the science of understanding the human body to the next level by looking at molecular biology, macromolecular structures and genomics. Bioinformatics could be the key to understanding how pharmaceutical treatments differ between individuals, thereby laying the foundations of personalised medicine. Advances in artificial intelligence, and as our understanding of the relationship between genotype (germline) and phenotype (somatic) genetics improves, the utility of bioinformatics is likely to accelerate.

> "The neural revolution could be part of driving advances in human well-being that exceed those brought about by the industrial and digital revolutions.
>
> The Royal Society, iHuman Perspectives, September 2019

13 Bayat, A., (2002), *British Medical Journal* (Clinical research edition), 'Science, medicine, and the future: Bioinformatics'.

Precision medicine – the future of health care

According to the Precision Medicine Initiative, a United States National Institutes of Health endeavour, precision medicine is 'an emerging approach for disease treatment and prevention that takes into account individual variability in genes, environment, and lifestyle for each person'.



Eesti Geenivaramu

The Estonian Genome Center is a research venture of the University of Tartu. The aim is to create a database of health, genealogical and genome data representing 5% of Estonia's population. The database will make it possible for researchers to look for links between genes, environmental factors and common diseases. The results of this research are likely to lead to new discoveries in genomics and epidemiology, and will be instrumental in increasing the efficiency of health care.

Brain interfaces

The science of decoding electroencephalogram signals from the brain is advancing and could present huge opportunities to integrate the processing power of machines with the cognitive power of the human brain. Brain interfaces, also known as neural interfaces or brain computer interfaces, enable direct communication between brain and computer. They can be one-way (for example, to understand brain function) or two-way (for example, to create a control and feedback system or a thought transfer system involving donor brain-computer-receptor brain).

Examples of one-way interfaces include the hearing aid. Two-way interfaces are at a very early stage of development and have achieved only limited results in narrow laboratory conditions. The most advanced examples, which have demonstrated the ability to transfer information, have been with animals,[14] and limited thought-speech translation in people.[15] Non-invasive brain interfaces have also demonstrated human-to-brain communication and problem solving.[16] Neurostimulation can be used to change brain function.

14 Pais-Vieira, M., et al., (2013), *Scientific Reports*, 'A brain-to-brain interface for real-time sharing of sensorimotor information'.

15 Anumanchipalli, G. K., et al., (2019), *Nature*, 'Speech synthesis from neural decoding of spoken sentences'.

16 Jiang, L., et al., (2019), *Scientific Reports*, 'BrainNet: a multi-person brain-to-brain interface for direct collaboration between brains'.

External brain interfaces

Non-invasive neural interfaces have been developed to expand human bandwidth and transform the way we interact with devices. These multi-billion dollar projects are using advanced machine learning techniques to accelerate development and are particularly interested in exploring how interfaces can redefine the augmented reality/virtual reality experience.



Internal brain interfaces

Several companies, as well as military research and development organisations, aim to develop a high-bandwidth data connection between brain and computer. One company has so far developed a neurosurgery robot capable of implanting flexible polymer threads – each the width of a human hair fitted with 32 tiny electrodes – into the brain with micron precision in a 45 minutes procedure. The threads feed into a small, low-powered implant that amplifies and digitises the brain signals for broadband speed streaming. The technology is currently being used for research on rodents and is intended as a prototype for future human use.



Non-invasive methods of neurostimulation, such as transcranial magnetic stimulation, use electrical means to increase or decrease the excitability of areas of the brain, potentially affecting mental processes such as neural plasticity and memory, attention, creativity, and many others. Neurostimulation has the benefit of being relatively non-invasive (although success correlates with placing electrodes accurately over the right area of the brain) and, so far, appears safe. It is also a flexible system but can only work on functions located in regions of the brain close enough to the skull wall. It is notable for being used by DIY 'brain hackers' and, reportedly, by some professional athletes.

Future opportunities. The potential applications of brain interfaces are staggering. Therapeutic benefits could include: cure of paralysis; restoration of sight and hearing; mental health management; and treatment for Alzheimer's disease. Brain interfaces could also be used as powerful diagnostic tools and inform the development of other human augmentation technologies and methods. In terms of augmentation, brain interfaces could: enhance concentration and memory function; lead to new forms of collaborative intelligence; or even allow new skills and knowledge to be simply 'downloaded'. Manipulating the physical world with thoughts alone would also be possible; anything from a door handle to an aircraft could, in theory and more recently in practice, be controlled from anywhere in the world.

Future challenges. There is still a huge amount that is not known about the brain. It has not yet been possible to combine stimulations to achieve more complex functionality, nor has it been possible to target specific brain areas with absolute confidence outside of controlled conditions. Interpretation of low intensity brain signals emanating from the proximal surface of the brain is achievable but capturing complex signal from deep brain functions without insertion of electrodes is as yet unachievable. There are also risks that brain interfaces could be hacked into and exploited by malign actors.

Pharmaceuticals

Pharmaceuticals play a role in many important forms of augmentation including physical, cognitive, emotional, motivational and sensory processes. Pharmaceuticals are one of the oldest forms of human augmentation. Cognition-enhancing pharmaceuticals range from caffeine, nicotine and various herbal supplements, through to stimulants such as amphetamines, methylphenidate and modafinil. These typically affect simple, low-level functions such as alertness and memory rather than high-level intelligence. Other types of cognitive augmentation include modulation of blood glucose and hormones, such as adrenaline and testosterone.

Pharmaceuticals that enhance physical performance include anabolic steroids, which stimulate muscle growth (although they can have unpleasant or even deadly side effects). Creatine has been proven to deliver increased power output and fatigue resistance, while at the same time it increases the risk of being overweight and injury. Erythropoietin (EPO) is a hormone produced mainly by the kidneys and has been synthesised and used illegally in sport to boost performance by increasing oxygen retaining capacity in the blood. Performance gains can be impressive but the side effects – even in cases that are carefully controlled – can cause blood clotting, stroke and even death. Meldonium is a drug legally prescribed to treat coronary artery disease but has been used by athletes (and Soviet soldiers in the 1979 Afghan War) – to enhance physical performance. Meldonium does, however, come with adverse side effects such as nausea, headaches and dizziness.

Most performance enhancing pharmaceuticals have their origins in medicines or are attempts to upscale the presence of naturally occurring chemicals in the body. However, their use as enhancements, even in professional sport, lack sufficient understanding to gauge dosage and quantify the effect. Although pharmaceuticals have applicability to all three areas of human performance, they often come with side effects that negate the potential gains. Currently pharmaceuticals have only limited use in human augmentation but developments in biotechnology, nanotechnology and bioinformatics could allow new pharmaceuticals to be designed that have more powerful and precise effects.

Section 4 – Additional technologies

Exoskeletons

Exoskeletons are external, removable structures capable of supporting the human musculoskeletal system and have been in development for decades. They are categorised as either active (powered) or passive (unpowered). The driver for exoskeleton development has been to restore or improve mobility for therapeutic reasons, but industrial and military applications are becoming increasingly common. Passive exoskeletons can ease the load on the body and reduce the risk of chronic occupational injuries. Active exoskeletons can translate brain signals into movement, or amplify the user's normal movement, to provide restorative or enhanced mobility and strength. Fuel cell technology has so far proven to be a bottleneck in active exoskeletons, but this is steadily being addressed. Providing amputees with functioning limbs has been a driver for the development of prosthetics. The most advanced prosthetics use implanted microelectrodes to provide a two-way interface allowing the user to control and receive tactile sensations.

Exoskeleton technologies are improving quickly, and the industry is attracting investment. This mutually reinforcing situation is likely to continue, leading to accelerated development. Current limitations include constraints on speed and range of movement, difficulty of entering confined spaces and the limitations of energy storage.

Exoskeleton technologies

Prosthetics. The University of Utah have developed a prosthetic arm that uses 100 microelectrodes to provide an interface with the user's nervous system. This technology has existed for over a decade but combining the robotics and electrode array for the first time has enabled the user to experience tactile sensations that are crucial when manipulating delicate objects.



Exoskeleton technologies (continued)

Unpowered. Passive exoskeletons can support able-bodied users' musculoskeletal movements to improve ability to manipulate heavy tools and reduce chronic occupational injuries.



Powered, non-invasive. Fully-powered robotic suits sense the user's normal movement to deliver super strength or increased endurance. Such suits have industrial or military logistics applications where heavy carriage is required (not combat).



Powered, semi-invasive. The University of Grenoble enabled a paralysed patient to walk again by using two wireless implants to interpret brain signals into robotic movements. The device was suspended from the ceiling to assist with balance but further user training and suit refinement will aim to remove this requirement.



Sensory augmentation

Sensory augmentation aims to extend the sensory range or acuity either by using gadgets or wearables to 'translate' external information for the human senses or by modification of innate senses. Information can be collected through a combination of sensors mounted or implanted on the body. The senses can be extended by translating frequencies beyond the normal human range into frequencies that can been seen, heard or otherwise detected. This could allow the user to 'see' through walls, sense vibrations and detect airborne chemicals and changes to magnetic fields. More invasive options to enhance existing senses have also been demonstrated, for example, coating retinal cells with nanoparticles to enable vision in the infrared spectrum.

Cross reality

Cross reality is an umbrella term for virtual reality, mixed reality and augmented reality, and is an area likely to see major growth.[17] Cross reality has been used in military aviation for decades in the form of head-up displays, monocles, helmet systems and flight simulators but falling costs are beginning to bring this expensive technology into wider applications. Virtual reality uses headsets and other wearables to provide an immersive experience of a computer-generated environment, while augmented reality superimposes computer-generated images onto the user's view of the real world, usually using glasses or a headset.

Virtual reality is becoming widely used for education, medicine, gaming and entertainment and augmented reality is increasingly used in advertising and retail. Defence applications could include training (virtual reality) and for improving situational awareness on operations (augmented reality). Tele-existence is a natural progression from cross reality and can be used to manipulate robots from a distance, often using a headset and haptic gloves for tactile feedback. Telemedicine is paving the way in this field, allowing doctors to remotely diagnose and, in some cases, perform surgery. Cross reality looks set to have an increasing role in industry and Defence, although energy sources, processing power and broadband speeds currently limit the technology's utility. Data networks are the emerging single point of failure for cross reality systems and protecting the network's integrity will be vital for any Defence applications.



First generation virtual reality headsets relied on processing power from a tethered desktop computer, but the latest versions are fully standalone and significantly widen application opportunities

17 Global cross reality investment in 2020 is forecast to increase by 78.5%. Forbes.com.

Cross reality in the military



The UK's Royal Navy is working with industry to develop an augmented reality system that could enable ships to be operated from the land. It is also trialling augmented reality glasses on the bridge of its frigates to improve situational awareness, increase efficiency and mitigate adverse environmental conditions.



The augmented reality systems in warfare could include overlaid information on friendly, enemy and civilian locations, geography and weapon engagement zones. This enhanced understanding could improve the speed and quality of decision-making, as well as the application of military capability.

Section 5 – Linked technologies

The potential of human augmentation is significantly enhanced when used in combination with other fields of science. Often mentioned in this context is nanotechnology, biotechnology, information technology and cognitive science (NBIC). This refers to the expected synergy of advancements in these four fields of technology. Nanotechnology, artificial intelligence and 3D bioprinting are discussed here as specific examples.

Nanotechnology is the term given to those areas of science and engineering where phenomena that take place at the scale of individual atoms (dimensions in the nanometre scale) are used in the design, production and application of materials, structures, devices and systems.[18] While there have been advances in some niche areas, overall progress has been slower than expected. This is principally due to concerns about the harmful effects of nanoparticles accidentally released into the environment and the siloed nature of science and engineering.[19] More integrated practices and artificial intelligence-enabled testing to address safety concerns is, however, likely to accelerate progress. Nanotechnological systems have significant potential for human augmentation technologies, for example, the use of energy or chemical transducing nanoparticles to

18 Further information can be found at https://ec.europa.eu/health/scientific_committees/opinions_layman/en/nanotechnologies/l-3/1-introduction.htm

19 The initial vision of mechanosynthesis for engineering molecular machinery (outlined in Drexler, K. E., (1992), *Nanosystems: Molecular Machinery, Manufacturing, and Computation*) motivated research projects in the 1990s that were to a large extent implemented by scientists in chemistry and material science interested in studying nanoscale phenomena but sceptical about and unable to produce engineering solutions (due to the fundamental difference between science and engineering and sociological border-work). See Drexler, K. E., (2013), *Radical Abundance: How a Revolution in Nanotechnology Will Change Civilization* for a personal perspective of the affair.

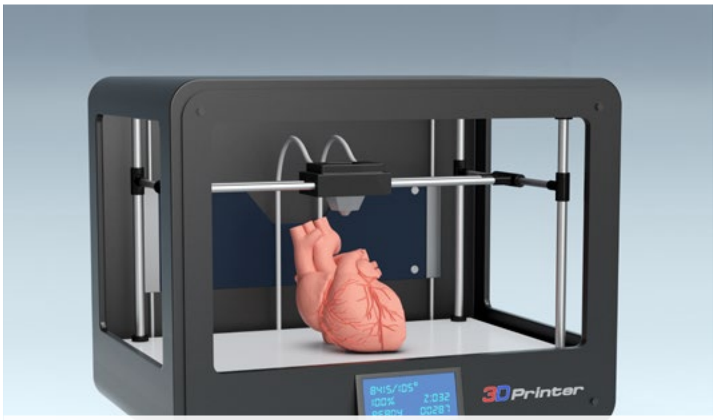
enhance sensors or the production of bespoke surfaces that act as a neural interface for implants.[20] Nano-systems have the potential to reduce the size of many human augmentation-related components. Longer-term possibilities include replacing organs with functionally equivalent or better systems, as well as adding new capacities, such as 'nano-blood'.[21] Such developments though are likely to be some way off.

Artificial intelligence is perhaps the biggest technological wildcard. It is extremely likely that even current machine learning techniques will have a transformative effect on many areas (for example, medical diagnosis, surveillance, management and robotics). Artificial intelligence could allow software to be developed that could:

- perform calculations or simulations via a brain interface to free-up human brain capacity;
- learn individual abilities and quirks to provide customised support and control of enhancements; and
- enhance ethical decision-making, which may also have significant implications in a military setting.[22]

It is likely that artificial intelligence will develop at a faster pace in the coming decades than it did in the past decade. Even if it were to 'only' advance at the present rate we should still expect a huge increase in 'implementation capacity' – the ability to design, develop, deploy and adapt new technologies, including those relevant to human augmentation.

3D bioprinting is a form of additive manufacturing that layers biological material to produce biological structures. It has successfully been used to produce skin, bone and heart tissue for transplants. Although at an early stage, the technology could be used to produce complex organs in the future. In the longer term, 3D bioprinting has the potential to dramatically improve the success of transplants by producing organs tailored to an individual's biology.



Complex bioprinted organs are still some way off; heart structures have been printed at small scale but are not yet practical

20 Kozai, T. D. Y., et al., (2012), *Nature Materials*, 'Ultrasmall implantable composite microelectrodes with bioactive surfaces for chronic neural interfaces'.

21 Freitas Jr, R. A. and Phoenix, C. J., (2002), *Journal of Evolution and Technology*, 'Vasculoid: A personal nanomedical appliance to replace human blood'.

22 Giubilini, A. and Savulescu, J., (2017), *Philosophy and Technology*, 'The Artificial Moral Advisor. The "Ideal Observer" Meets Artificial Intelligence'.

Section 6 – Employment considerations

Discussion of technology in isolation is necessary to understand what is possible but it will be the practical, ethical, legal and social viability that fundamentally informs its usability. Understanding potential side effects and interactions with other aspects of human performance, task, organisation and environment will be key to assessing the benefits of human augmentation and informing further research and experimentation. For example, improved body armour increases resilience to blast, fragmentation and gunshots, but reduces speed, manoeuvrability and situational awareness. The second order effects of wearing body armour could, in some cases, negate the intended effects; the same could be true for human augmentation technologies if the employment considerations in Figure 5 are not observed.

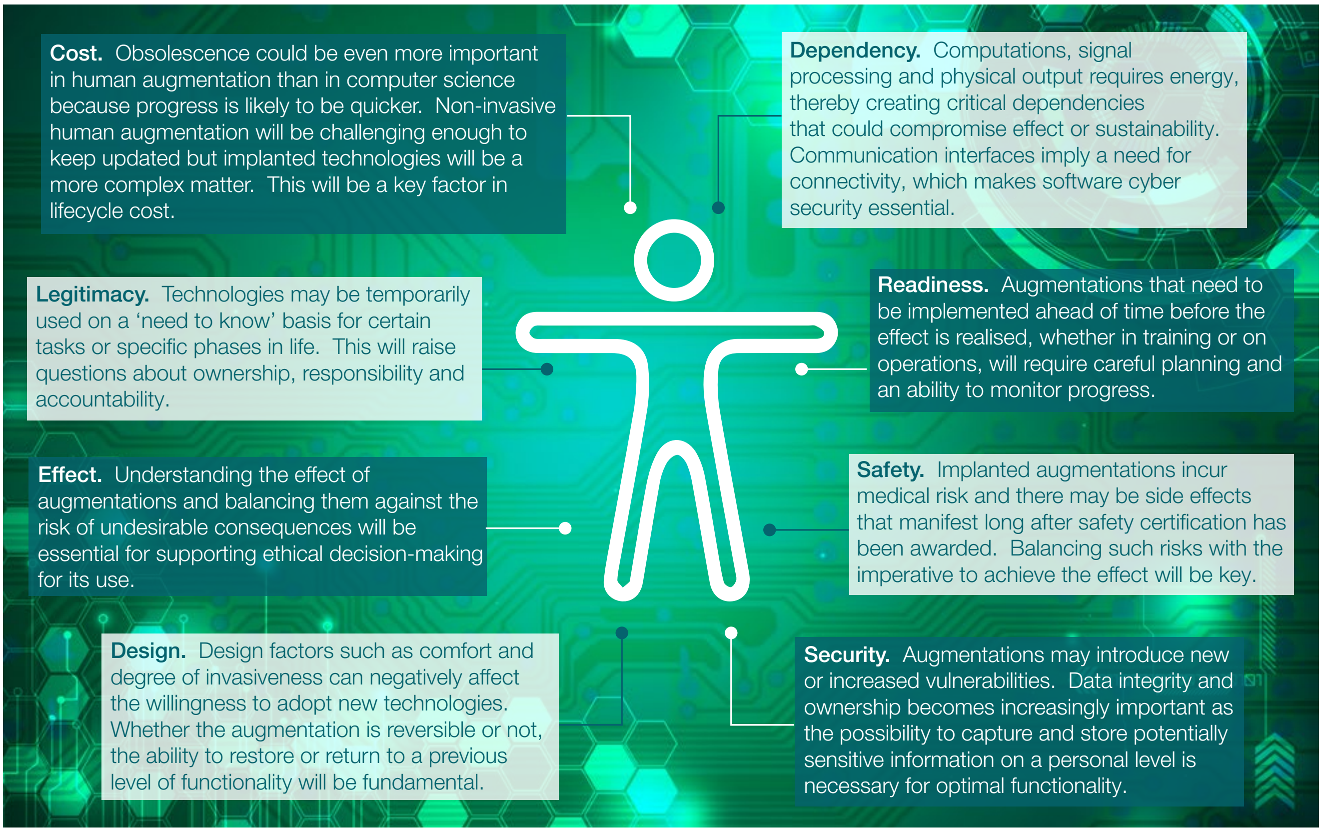


Figure 5 – Employment considerations

Section 7 – Feasibility assessment

By considering human augmentation technologies in terms of their current technical maturity and the magnitude of policy considerations it is possible to get a broad sense of opportunities for today and for the future. The matrix at Figure 6 illustrates the following conclusions and at Figure 7 are estimated realisation timescales for various augmentation technologies.

a. There are mature technologies, capable of delivering transformational effects, that could be integrated today with manageable policy considerations.

b. The most transformative technologies (for example, genetics and brain interfaces) currently sit at a relatively low level of maturity and their implementation would have significant policy considerations. The potential impact of these technologies, however, means that Defence should monitor them closely and be ready to seize opportunities as they arise.

c. Pharmaceuticals are widely thought to be the archetypal performance enhancers, but this field is changing rapidly and new developments in brain chemistry, psychochemicals, neuropharmaceuticals, cell and gene therapies should be followed closely. Medical countermeasures are also relevant since aggressor states and/or lone actors might find these options easier to employ.

d. None of the human augmentation technologies exist in a bubble and there are linkages between many of them. Bioinformatics and collection and analytics (encompassing sensors and artificial intelligence-enabled processing) are relatively uncontroversial but with a high transformative potential. In addition, they will support the use of other human augmentation technologies, as illustrated by the shading on the matrix.

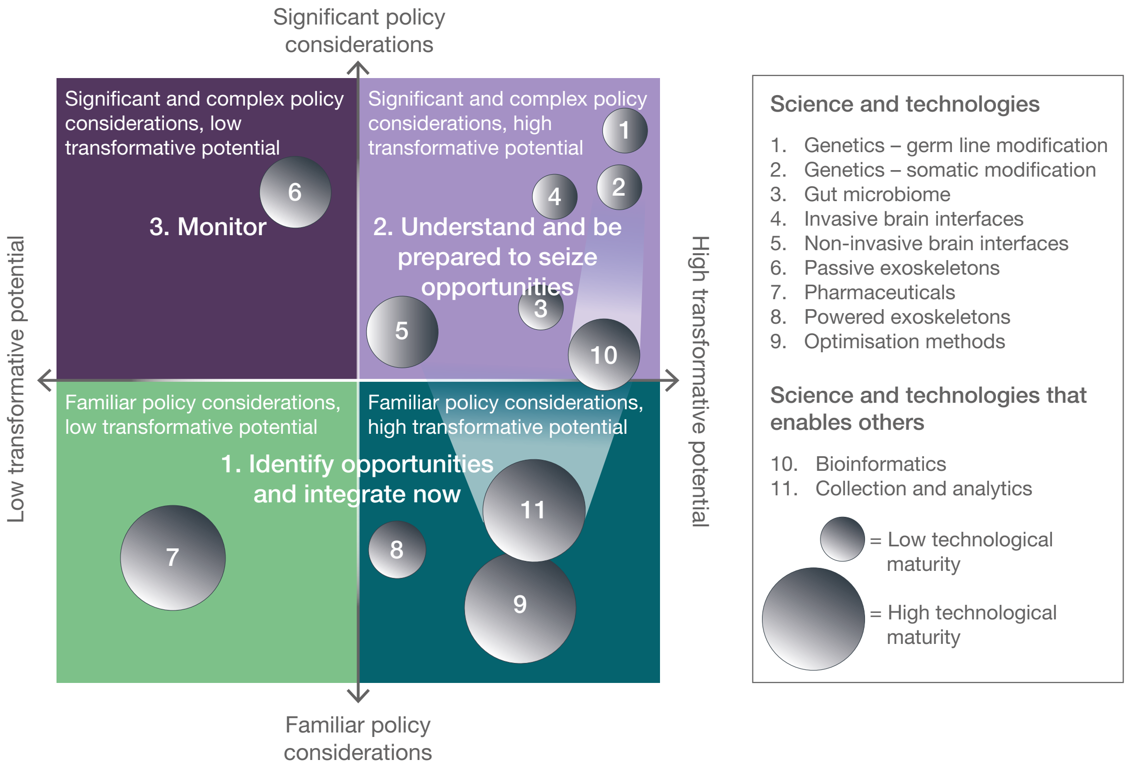


Figure 6 – Feasibility assessment

1) Acceptance for human augmentation in society will set the pace for development of new capabilities.
2) There will be ethical/moral thresholds inintroducing new technologies to individuals and society.
3) Reversibility will be one of the main factors to consider.



The timescale is based on the assumption that the technology/method:
- is fully functional, meaning that it gives desired effect and associated issues have been addressed properly; and
- is usable in the field (proven military use).

Figure 7 – Realisation of human augmentation timescale

Key deductions and insights

- Continued investment to understand the human body will be critical to the success of human augmentation. Lack of understanding is, currently, the major bottleneck.
- The use of science and technology to optimise human performance has significant potential to deliver transformative effects.
- Of the four core human augmentation technologies, genetic engineering shows the greatest potential. Although a controversial technology it is entering a period of rapid development.
- Safer methods such as CRISPR are beginning to change the ethical standpoint on genetic engineering.
- Brain interfaces are attracting significant funding and have potential to deliver radical enhancements.
- Non-invasive brain interfaces offer a balance between transformative performance and ethical acceptability.
- Pharmaceuticals are one of the most prevalent forms of augmentation and a field that is rapidly changing. Pharmaceutical effects are modest in comparison to the potential of genetics and brain interfaces and adverse side effects often negate their benefits.
- Using human augmentation technologies will create new dependencies, support and delivery requirements that must be factored into planning at an early stage of their development.
- The transformative potential of human augmentation technologies lies in effective combination with linked fields of science.
- Human augmentation is developing rapidly and close relationships with industry will be needed to understand and exploit emerging opportunities.
- Much development is affected by public attitudes, corporate liability and what is classified as legitimate research. Changes in these factors will have a significant influence on the pace of future development.

Notes


ETHICS

Part 3

Ethical considerations

The ethical and moral implications of human augmentation are profound, and Defence will need to engage early and regularly with the full range of stakeholders to understand and inform the debate.[23] Does human augmentation go against nature and undermine people's dignity by robbing them of the ability to live a 'natural', 'authentic' life? Will the 'value' and meaning of our lives lessen if we no longer need to overcome hardship? Or will the ability to live longer and healthier lives enable us to reach new heights of intellectual and creative enlightenment, thereby elevating dignity and increasing meaning? Part 3 will not seek to answer these questions as they rightfully continue to be the subject of wider debate – instead it will focus on those themes that are pertinent to Defence.

Morality

There are universal aspects of morality that underpin the basic functioning of all societies, but their interpretation varies. The idea of helping your family and group, respecting others' possessions and returning favours are deep-rooted altruistic tenets that helped our ancestors form successful social groups. These concepts are still the foundation of today's ethics.[24] But behind these tenets are a myriad of local factors and interpretations, hence concepts of morality vary across cultures. Attitudes towards human augmentation could, therefore, vary significantly between and within nations. Nations that form alliances on defence and security issues may, therefore, be deeply divided on their stance towards human augmentation.

Perspectives

Perspectives can change quickly and will affect the rate of human augmentation development and acceptance. Throughout history the number of entities that have a moral 'value' has been growing: a trend known as the 'expanding moral circle'.[25] People of different nationality, ethnicity, gender, religion and sexual orientation, even animals, are increasingly 'in the circle' as moral perspectives change. The information revolution – from print press to tweet – is also accelerating the speed and scale of moral change as different behaviours and attitudes become normalised through exposure.[26] We must be careful to distinguish genuine from fake information as, for example, the view that fifth generation (5G) cellular networks somehow are responsible for the spread of COVID-19; this has been believed by many impressionable people. The impact of legislative changes on moral beliefs is also important, with some evidence suggesting that changes to

23 The terms 'ethics' and 'morality' are used interchangeably here. Some disciplines use ethics to refer to societal codes or principles, and morality to refer to an individual's own moral beliefs, but this distinction is not used in this publication.

24 Curry, O., et al., (2019), *Current Anthropology*, 'Is It Good to Cooperate?: Testing the Theory of Morality-as-Cooperation in 60 Societies'.

25 Singer, P., (2011), *The Expanding Circle: Ethics, Evolution, and Moral Progress*.

26 Bear, A. and Knobe, J., (2017), *Cognition*, 'Normality: Part Descriptive, Part Prescriptive'. Perhaps the most notable example of this is the legalisation of gay marriage and increasing acceptance of lesbian, gay, bisexual and transsexual (LGBT) in mainstream media and culture – a change that has largely taken place in less than a generation.

morality are often caused by legislative changes.[27] Defence, however, cannot wait for ethics to change before engaging with human augmentation, we must be in the conversation from the outset to inform the debate and understand how ethical views are evolving.

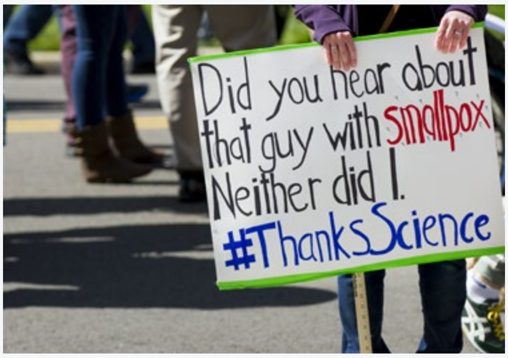
Vaccines – how attitudes can vary

The history of vaccinations demonstrates how proven, and seemingly uncontroversial human augmentation technologies can take many years to become globally effective and accepted by societies. The discovery of the smallpox vaccine at the end of the 18th Century saved millions of lives but was condemned by some of the world's leading thinkers. Emanuel Kant, for example, warned that humans would be infected with 'animal brutality' in the vaccine process, which used secretions from cowpox to provide immunity. Notwithstanding the effectiveness of the vaccine, it took 130 years for smallpox to be officially eradicated in 1979.

Today, vaccines are still rejected by sections of society whose caution and/or scepticism stems from a belief that such treatments are an invasion of their physical integrity, or the risk of side effects (real or perceived) are not equal to the benefits of immunity. The ongoing global fight against measles is an example of how rejection of vaccines by certain communities can allow outbreaks to continue, despite a vaccine being in existence for over 50 years.

This example shows that we cannot assume human augmentation will be automatically effective or accepted in its intended use, no matter how beneficial its effects may be. Human augmentation may be resisted by elements of society that do not trust the effectiveness and motive of the augmentation. This will increase the need for dialogue between society, industry and the state.





27 Kenny, C. and Patel, D,. (2017), Center For Global Development, *Working Paper 465*, 'Norms and Reform: Legalizing Homosexuality Improves Attitudes'.

Safety

The safety of a technology, especially one that is highly invasive and/or poorly understood, is a critical ethical constraint. The risks and side effects of undergoing chemotherapy are typically high, however, when compared with consequences of not undergoing it, it is usually judged to be worthwhile. In contrast, augmentation technologies that entail high risks to deliver minor benefits are unlikely to be judged as worthwhile. Safety risks are particularly difficult to weigh up in a military context; for example, brain interfaces and exoskeletons designed to enhance performance (and survivability) could inadvertently create vulnerabilities to hacking, jamming and mobility in confined positions.

Obligations

There may be a moral obligation to augment humans in cases where it promotes well-being. Foetuses are already screened for an array of diseases – and, in the future, technology may be able to quantify the child's chances of developing cancer or having low intelligence. If the technology existed to change these outcomes, would society be obliged to use it? In a military context, will it be necessary to enhance our troops to give them protection against a novel threat? Is it moral to have super-elite soldiers with human augmentation but not offering it to one and all?

The notion of moral enhancement may require using human augmentation in the future.[28] Our moral psychologies evolved when our actions only affected our immediate environment, but recent advances in technology mean that actions can have almost immediate global consequences. Our moral tendencies to look after our kin and immediate future may no longer be fit for the modern, interconnected world.

National interest

The imperative to use human augmentation may ultimately not be dictated by any explicit ethical argument, but by national interest. Countries may need to develop human augmentation or risk surrendering influence, prosperity and security to those who do. This possibility is encapsulated by investment in artificial intelligence and gene editing. Some countries are investing heavily into private artificial intelligence companies, with annual investments worth US $1 trillion by 2030.[29] Similarly, enormous funds are being invested in gene editing by countries with citizens who are more accepting of the technology. Countries that invest in artificial intelligence and gene editing now are likely to reap significant returns. Public opinion, particularly in democracies, will be a major influence on a country's willingness to embrace human augmentation but neither public opinion nor ethicists are likely to decide the future of human augmentation. Instead, it is likely to be decided by governments based on the national interests in terms of prosperity, safety and security.

28 Savulescu, J., (2005), *Reproductive BioMedicine Online*, 'New Breeds of Humans: The Moral Obligation to Enhance'.

29 Forbes, (2020), 'Why The Race For AI Dominance Is More Global Than You Think'.

Key deductions and insights

- The core tenets of morality are universal, but interpretation varies across cultures. Adopting human augmentation will therefore be uneven, and we should be prepared for allies and adversaries to exploit human augmentation in different ways.

- Ethical perspectives are changing faster and more radically as a result of growing access to information. Defence cannot wait for ethical views to change before exploiting human augmentation; it must join the conversation now to ensure it is at the leading edge of the field.

- Safety versus potential benefit is the critical factor for employing human augmentation. This equation is more complex in a military context where the causal link between safety and risk must also consider the adversary and operational context. Defence must engage early and regularly with human augmentation development to ensure that these unique ethical factors are considered. Defence should also consider how to counter human augmentation developments introduced by adversaries.

- Human augmentation could exacerbate existing inequalities and create new divisions. International dialogue and regulation of human augmentation technologies will be critical in averting this potential outcome.

- There could be an increasing moral imperative to use human augmentation if it offers ways of safely improving our well-being. Militarily, there may also be an obligation to protect against or match human augmentation fielded by adversaries.

- Ethics will be a critical aspect when considering whether to adopt human augmentation, but national interest will also inform, and may even fundamentally reshape, the moral calculation. There is likely to be a fine balance between upholding the ethics that underpin our way of life and avoiding ceding an unassailable national advantage to our adversaries.

Notes



Part 4

Legal considerations

The legal considerations associated with human augmentation technologies are numerous, spanning international and domestic, public and private, and civil and criminal law. Part 4 briefly considers some of the key legal complexities to illustrate issues that will require careful consideration now and in the future.

Human rights

Human rights and property law are examples of legal fields which may need to adapt as technologies become integrated with, rather than merely used by, people. People have legal rights and machines do not, but human augmentation will make it increasingly difficult to adopt this binary approach as machines are integrated with our bodies – potentially at a molecular level. An example is the discussion about possibilities that humans may become cyborgs in the future.[30] The term has many mythical, metaphorical and technical connotations, but it reflects the idea that humans no longer merely use machines – we increasingly depend on them for our most human-like activities.[31]

Ownership of human augmentation technologies, and the data they use and collect, will need to be carefully considered if implants become integral parts of our bodies. For example, people who wear pacemakers often do not have any rights to access data gathered and transmitted by these devices. Within the European Union this problem is in part managed by the privacy law General Data Protection Regulation (GDPR), which regulates access to personal data. There are also varying rights of third-party access to such data, which will become increasingly valuable (and exploitable) in the future. If not effectively regulated by law, such areas of inconsistency and/or ambiguity create the potential for individual privacy to be breached through what could become to be known as 'under-skin' surveillance methods. It is plausible that device ownership becomes an issue if immaterial property rights prevents unlimited use, or the individual is not the legal owner of an integral part of their own body.



Human augmentation may require humans and cyborgs to be legally distinguished in the future

30 Cyborg is defined as: a fictional or hypothetical person whose physical abilities are extended beyond human limitations by mechanical elements built into the body. *Concise Oxford English Dictionary*, 12th Edition.

31 Wittes, B. and Chong, J., (2014), Brookings.edu, 'Our Cyborg Future: Law and Policy Implications'.

The Law of Armed Conflict

International law[32] encompasses many fields relevant to human augmentation, most notably the Law of Armed Conflict (also known as international humanitarian law). This is underpinned by the four fundamental principles of military necessity, humanity, distinction and proportionality. Each of these principles could be affected by human augmentation both positively and negatively. In a positive sense, it may improve compliance with the principle of distinction by improving combatants' ability to identify legitimate targets through improved cognition and situational awareness. It could also improve compliance with proportionality by allowing more precise targeting of threats, thus minimising incidental or collateral damage. But use of human augmentation that modifies human emotions may lead to contradictory outcomes: it could improve compliance with the principle of military necessity by preventing wanton killing or destruction born out of fear or desire for revenge; but it could also undermine compliance with the humanity principle by suppressing emotions that prompt empathy, compassion and treatment of wounded enemy or civilians. Development of human augmentation technology will need to carefully consider international law to ensure that these issues are successfully navigated.

Augmented combatants could constitute a new means or method of warfare if, for example, soldiers became the delivery mechanism for nano or biotech weapons. Existing conventions might prevent the latter, but consideration of the Biological and Toxin Weapons Convention (BTWC) shows a level of ambiguity that could be exploited with BTWC technology. The BTWC is not explicit on whether 'agents' are limited to microbial size, nor if they are specific to those levelled at an adversary, or to enhance one's own personnel. Such ambiguity may need to be clarified as human augmentation becomes more capable.

Accountability and responsibility

Legal liability – whether criminal or civil – is often more complex in a military than a civilian context because of armed forces' hierarchical structures: superiors can be liable for the acts of their subordinates. This has long been the case, but increasingly capable human augmentation could amplify the importance of such issues. If, for example, a commander orders a subordinate to take a stimulant with a known side effect of impaired decision-making, the commander might incur some liability for any harm caused as a result. Human augmentation may also make it difficult to establish proof of liability for a crime. For example, combatants that would have ordinarily been found guilty of a crime may be able to cite their use of human augmentation – as ordered by their chain of command – as a key factor in their actions (whether true or not), thereby raising doubt about the legal standard of proof required for their conviction. Questions as to whether liability for the upkeep of augmentations such as prosthetics or irreversible implants lies with the state or the augmented individual, both during and after the individual's military service may also arise.

32 International law creates legal obligations for states through established customs or treaties.

Autonomy and consent

Consent in the military is necessarily different to consent in wider society due to the unique relationship between subordinates and their superiors. It could be difficult for military personnel to give sufficiently voluntary and informed consent due to a tendency to follow orders over individual interest.[33] Would a Serviceperson who refused to be augmented be guilty of disobeying a lawful command? If augmented against their will, would it amount to an assault or human rights abuse? How can Defence exploit the benefits of human augmentation without inadvertently abusing the trust of its people? Human rights is an example of a legal field which may need to adapt as technologies become integrated with, rather than merely used by, people.

Variance and compliance

States' freedom to decide whether to enter into treaties means that their international law obligations vary. Similarly, domestic laws vary significantly between states. It will therefore be difficult to establish an international 'level playing field' for using human augmentation technologies. Even if there were an internationally agreed legal framework, recent history has shown that a state's willingness to observe it is not guaranteed. There are obvious implications for interoperability with allies and freedom of manoeuvre relative to potential adversaries. The uneven legal landscape should be considered when planning to use or counter human augmentation capabilities.

Legal evolution

Some human augmentation technologies, such as wearables or exoskeletons, are likely to be incorporated relatively easily into existing legal frameworks. Others, such as human genome editing, will be more contentious and may be either prohibited or restricted by existing law. Novel technology with potential for military use, which causes serious ethical concerns, can be expected to spark calls for new international law to prohibit or restrict it, as illustrated by the current discussions about lethal autonomous weapons systems in the United Nations.[34] Countering human augmentation technologies introduced by an adversary could also be considered offensive rather than defensive actions depending on the legal definitions agreed internationally.

Law is not immutable, so what is permitted or prohibited today might not be in the future. Existing law can evolve and new law be created in response to changes in societal values and technological developments. However, the creation or amendment of law tends to happen slowly, and the law usually lags some way behind technology. Those involved in developing or procuring military human augmentation capabilities should engage early and frequently with relevant legal experts.

33 Mehlman, M., et al., (2013), *Case Legal Studies Research Paper No. 2013-2*, 'Enhanced Warfighters: Risk, Ethics, and Policy'.

34 It should not, however, be assumed that new technology requires new regulation as existing regulation (including legal reviews under Article 36 of the First 1977 Protocol Additional to the Geneva Conventions of 1949) may be sufficient.

Key deductions and insights

- Human rights law does not recognise the increasingly blurred line between humans and technology. This will have important implications for how human augmentation is adopted in the future, particularly with regard to privacy and protecting our way of life.
- Accountability for the actions of augmented individuals, particular in a military context, will be complex and will need to be understood at all levels of command.
- Liability for military augmentations is likely to extend beyond the Serviceperson's career. How this is legally managed will require careful consideration.
- Human augmentation of the future could have both beneficial and adverse impacts on compliance with the principles of necessity, humanity, distinction and proportionality – technologies that bolster one, may denude another.
- Human augmentation may require revision of the conventions of war if augmented combatants are deemed to constitute a new means or method of war.
- Voluntary and informed consent will be very challenging to achieve in a military context, where a hierarchical culture and predisposition to obey orders could conflict with human rights.
- Irrespective of international and domestic laws related to human augmentation, history has shown that compliance will vary based on culture, political ideology and national interest. The legal playing field will be uneven.
- States' differing legal obligations and constraints have implications for interoperability with allies and freedom of manoeuvre relative to potential adversaries.
- Law is not immutable but change tends to be slow – early and regular engagement with legal experts is required of those developing or procuring human augmentation technology.

Notes



Part 5

Implications for society

Our innate curiosity and desire to test the limits of human capability have acted as drivers for development throughout human history. Commercial and individual interests will be key drivers for human augmentation development over the next 30 years and the implications will be far reaching. Part 5 will focus on the most relevant and profound implications, noting that separate parts cover ethical and legal implications.

Economic

Economic interests will heavily influence the direction of human augmentation development and they are likely to differ from society's interests.[35] The private sector invests more in research and development and has greater organisational agility than state institutions, meaning it can employ the best researchers to stay at the cutting edge of human augmentation research. Developing enhancements is likely to be highly profitable but activities will focus on the most lucrative activities and not necessarily on those that deliver the greatest benefit to humanity. The tension between states, societies and market forces is nothing new, but the consequences of mismanaging a technology as potent as human augmentation could be profound.



Economic interests will heavily influence the direction of human augmentation development

35 Society as the entirety of all people who live under certain political, economic and social conditions. This publication refers to Western liberal societies in its discussion, noting that impacts in other societies will vary.

Inequality

Without intervention, human augmentation is likely to exacerbate inequality, and could lead to societal tensions. The wealthy are expected to be early adopters of human augmentation and they could use their acquired superior abilities to entrench their status. In time this could lead to an elite overclass that could become genetically distinct from the rest of humanity,[36] and leave an unaugmented underclass as relatively disadvantaged as the illiterate are in today's societies. As human augmentation technology matures governments and international institutions will be forced to grapple with these possibilities. Whether they should step in to ensure equal access to human augmentation or, like the growth of car ownership through the 20th Century, let market forces decide is likely to be a hotly debated issue.

Acceptance

Many factors, including its purpose, effectiveness and safety, will influence acceptance of human augmentation. An individual's acceptance is a crucial factor for implementation and the challenge for societies will be to strike a balance between scientific curiosity, the common good and the individual's perspective. Human augmentation may challenge or offend religious views and appear to give credence to other belief systems, such as transhumanism.[37] These divergent views could lead to polarisation, social tension and, conceivably, conflict. The complex interplay between perception and acceptance will require careful engagement if the benefits of human augmentation are to be realised and pitfalls avoided.

Health and social care

Human augmentation will transform health and social care. Health care systems already use data and technology to prevent illness rather than reacting to it, and human augmentation will accelerate this shift. Implanted sensors could allow early detection, and artificial intelligence-enabled diagnosis and treatment could be delivered remotely by doctors using telemedicine. The ability to interpret genetic information is still developing but could give rise to powerful tools to understand individual health risks. Genetic therapies of the future could correct issues before they manifest into an illness. These early interventions would reduce demand for face-to-face clinics and hospital admissions, potentially reducing the infrastructure needed to deliver health care. Preventative interventions are cheaper and more effective, meaning increased survival rates, shortened recovery time and less strain on the economy.

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36 Fukuyama, F., (2002), *Our Posthuman Future: Consequences of the Biotechnology Revolution*. Mehlman, M., (2003), *Wondergenes: Genetic Enhancement and the Future of Society*. Resnik, D., (1994), *Journal of Medicine and Philosophy*, 'Debunking the Slippery Slope Argument against Human Germ-Line Gene Therapy'.

37 Transhumanists believe that humankind can and should eradicate ageing as a cause of death, and that humans and machines should be merged to enhance the human condition.



Societies may seek to gainfully employ the elderly, but this could impact on the young and jobless

Life extension. People are living longer, putting stress on health, social and economic systems.[38] Human augmentation may exacerbate this issue by helping people to live even longer or it may alleviate pressure by improving health and productivity in old age. Most industrialised societies will face this challenge in the coming decades and Japan is at the forefront. Japan's strategy has been to focus investment on medical technologies such as regenerative medicine and cell therapy and to keep the elderly in the workforce, reducing pressure on health and social care – the areas where human augmentation could have a significant impact. Even if significant life extension remains elusive, it is likely that human augmentation will increase the number of years lived in good health, with huge implications for society.[39] Societies may seek to gainfully employ the elderly, but this could impact on the young and jobless; will the elderly be seen to take more than their 'fair share' of resources and opportunities?

Self-optimisation

Diffusion of human augmentation technology will increase societal interest in self-optimisation and/or enhancement, particularly in a world of increasing individualism and competitiveness.[40] DIY biohacking is a form of self-enhancement that has been practiced since the 1990s but the availability of increasingly sophisticated technology such as clustered regularly interspaced short palindromic repeats (CRISPR) 'home kits' will be a huge regulatory and safety challenge. Potentially, anyone with the right knowledge and tools could modify their DNA with attendant risks to themselves and others. The cosmetic surgery industry could also be highly disrupted by human augmentation and issues around safety and aftercare could be concerning. Some believe 'designer babies' are likely within the next 30 years. Individually driven efforts to push the ethical and technical limits of human augmentation in this way could lead to hyper-competition within societies and spawn a black-market trade in human augmentation with the attendant safety and security risks.

38 World Health Organization, (2018), 'Ageing and Health'.

39 Wheeler, H. E. and Kim, S. K., (2011), *Philosophical Transactions of The Royal Society B Biological Sciences*, 'Genetics and genomics of human ageing'.

40 Santos, H. C., et al., (2017), *Sage Journals*, 'Global Increases in Individualism'.

Body hacking – DIY augmentation

Biohacking is the biological, chemical or technical intervention in organisms with the aim of change and improvement. One area is body hacking, in which you penetrate the human body. People with DIY implants can pose a security risk if the implant can communicate with the surroundings.



Magnet implants were one of the first body hacks. Small magnets were inserted into the fingertips, for example. This not only resulted in an exciting effect when picking up small metallic objects, but also gave owners a new sense – to perceive magnetic and electrical fields.



Radio-frequency identification and near-field communication implants are popular biohacks. Once inserted, these ‘chips’ can be used for a great variety of identification purposes. They can replace many of our keys and passwords, allowing us to unlock doors, start vehicles, and even log onto computers and smart devices.



Implants on the surface of the skin gently vibrate whenever the wearer is facing magnetic north.



Light emitting diode (LED) implants can be used to create light effects for cosmetic purposes.

Education and work

Genetic profiling, bioinformatics and artificial intelligence could identify which methods of education are most suited to each individual, thereby enhancing learning. Students’ performance could be monitored more effectively (and intrusively), further improving education. Understanding innate individual characteristics could be used to inform career choices and some countries and institutions might be tempted to force people into careers identified as suitable.

Greater understanding of individual practices through wearables and analytics could improve productivity and workforce health, while augmentations could mitigate disabilities thereby allowing more people to work. Human augmentation will also enable older generations to remain active where, potentially free from parental responsibilities and possessing many years of experience, they could make a valuable contribution to society.

Human augmentation might also increase anxiety in the workplace, particularly if employees are intrusively monitored by bosses trying to increase productivity. People may also feel pressured to undergo human augmentation to compete for advantage in the workplace. While employers may benefit from, or even encourage, these trends there could be significant long-term cost to mental health and social cohesion.

Social cohesion

Human augmentation could help to improve social cohesion by increasing participation in society regardless of individual differences or impediments. Human augmentation could also allow people to connect in more intense and creative ways (for example, via linked brain machine interfaces). Human augmentation will also provide tools for people to express their individuality in more pronounced ways, potentially leading to a more diverse society. This could lead to more creativity, acceptance and innovation, but may also increase social fragmentation if people divide into different groups. For example, those who either reject human augmentation or use it for unusual applications could be marginalised, or even persecuted. Additionally, an augmented intelligent population may saturate the employment market and lead to swathes of highly capable young adults being obliged to take menial employment resulting in a sense of unfulfillment and frustration, leading to social tension.[41]

Safety and security

Human augmentation is founded on very personal (biological) data and the use of this data in many aspects of daily life will pose both significant challenges and threats to safety, security and privacy. The governance frameworks for securing data will need to be both national and international in nature, so that it can be easily shared but also protected. Some governments may use this data to exert control over their citizens, leading to new forms of oppression. Governments may also consider this data as a national security issue: such large and detailed data sets could be exploited for malign purposes.



Human augmentation is founded on very personal data

41 Early signs of this trend can already be observed in South East Asian countries.

Just as the Information Age has seen 50% of global crime move into cyberspace, human augmentation could see the human body become a medium of crime. While today's threats are relatively rudimentary, this will not be the case for long because of the rapid rate of development of many human augmentation technologies. The diffusion of human augmentation technology and the promise of what it might offer will create the perfect conditions for a black market, and related crime. Illegally produced and untested products are likely to present significant safety risks to society, for example, without safeguards genetic and nanotech augmentations could spread uncontrollably.

Key deductions and insights

- Economic forces will be a powerful influence on the rate and direction of human augmentation development, which may not always be in the best interest of society.
- Without careful management, unequal access to human augmentation will amplify existing societal divides.
- Societies' acceptance of human augmentation will be shaped by complex factors that will need to be carefully considered by proponents of human augmentation.
- Human augmentation will lead to major changes in health and social care with notable improvements in preventative health care likely.
- Human augmentation is likely to lead to a significant increase in the number of healthy years recipients can expect to live.
- In the future, anyone with the right knowledge and tools could indulge in DIY human augmentation, including modifying their own DNA. Balancing the rights of the individual with protecting society will be a complex dilemma for regulators.
- Human augmentation introduced early in life could improve education but could also be used for manipulation.
- Human augmentation should increase access to the job market, increasing workforce diversity and productivity but it could also be used for intrusive surveillance and lead to hyper-competitiveness, adversely affecting society.
- Society will become more diverse as people use human augmentation to express their individuality.
- Human augmentation will lead to new forms of crime that will require law enforcers to develop new capabilities.

Notes


LOADING

Part 6

Implications for Defence

The quest for advantage over adversaries has been the driver for the development of military platforms and technologies. The Biotech age, with human augmentation as a key component, will see focus on the human platform grow to match that of the machine. Part 6 uses the Defence capability framework of prepare, project, engage, sustain, direct, protect and inform to discuss what human augmentation could mean for Defence out to 2050.

Prepare

Civil-military collaboration will be vital. Relationships with industry and academia will be key to understanding how emerging human augmentation technologies could be repurposed or developed for Defence. Although not necessarily a model that Western defence organisations would wish to replicate, China's human augmentation experimentation is being led by the People's Liberation Army Academy of Military Science. The United States Defense Advanced Research Projects Agency's (DARPA) prominent role in the 'innovation ecosystem' is another example of how Defence organisations could foster more mutually supportive links with industry. Early civil-military cooperation will enable Defence to stay at the forefront in this rapidly evolving field.

Human augmentation is bringing about a securitisation of the life sciences, a field which has relied on a culture of openness and collaboration. Unlike nuclear physics or cryptography, human augmentation-related sciences have relatively little experience of classified research and its links with national security apparatus are less developed. The relationship between Defence and the life sciences will need to be revised as the dual-use of emerging human augmentation technologies becomes clear. Governments will need to work with the scientific community to establish a framework that safeguards and supports national security without undermining collaboration. This will also apply to relationships with other government departments responsible for health and social care, who are beginning to gather data and use technologies that may be the target of malign actors.[42]

Recruiting. Entry standards and screening processes will need to account for an expected increase in the use of human augmentation within society. This could be as simple as a declaration but trying to determine which human augmentation interventions have implications for a Service career is likely to be complicated. Defence will need increasingly skilled personnel and recruiting them will be difficult. Although, as human augmentation technology improves, it could enable more people to join the military, widening the pool of potential recruits.

42 See BBC Radio 4 Analysis, (2020), 'The NHS, AI and Our Data'. This podcast discusses how medical data may be accessed or stolen by potential adversaries seeking to understand more about the biology of the UK population.

Bioinformatics. Bioinformatics will identify an individual's strengths and weaknesses, and this is likely to change the way Defence recruits. Genetic profiling is a relatively cheap and effective way of identifying individual traits and Russia has already announced a plan to use it for its military personnel.[43] Even basic information, when gathered in large numbers, could be analysed using artificial intelligence to identify what career fields a recruit is most suited to.

Neural monitoring. Neural monitoring and neurostimulation technologies have the potential to radically improve training, including specialist areas such as pilot, special forces or language training. In the short term, neural monitoring could be used to understand how trainees' brains are processing their given task, thus providing instructors with insights to guide student development. In the future, brain interfaces could be used not just to monitor, but to also enhance training by precisely stimulating the areas of the brain relevant to the task. Pharmaceuticals and neurostimulation could enhance the skills of personnel and speed up training, thereby improving their readiness and effectiveness.

Unit cohesion. Unit cohesion is founded on social relationships, shared experience and training – it is a critical part of the willingness to fight. Human augmentation has the potential to change the foundations of unit cohesion and could, if not handled carefully, undermine it. For example, differing levels of augmentation within units could introduce stigma, suspicion or resentment of enhanced personnel.

Demobilisation. In addition to preparing personnel for operations they will need to be prepared for life after the military. For example, the use of invasive human augmentation may require surgery to remove or downgrade implants that may not be permitted in civilian life. Reintegration to society could be complicated from a technical perspective but learning to live without military-grade augmentations could present even bigger mental health challenges. Preparing to de-augment will be just as important as augmenting in the first place. Equally, veterans who have benefitted from human augmentation in Service life may be highly sought after by civilian employers.

Project

The ability to deploy force is being increasingly challenged by the proliferation of precision, long range and more lethal weapons. Part of the solution to this challenge will be lighter, more mobile and versatile forces, able to operate in a more distributed fashion and greater use of unmanned systems.[44] Human augmentation will directly support these solutions, enabling personnel to be more resilient in austere conditions and, through brain interfaces, increase the combat power they can bring to bear by networking them with autonomous and unmanned systems. In the longer term, tele-existence may see certain tasks (for example, trauma surgery and bomb disposal) performed remotely, removing the need to deploy certain personnel.

43 Forbes, (2019), 'Russia Will Genetically Test Soldiers To Identify The Best Fighters And Thinkers'.

44 The United States Marine Corps, *Force Design 2030,* 12 March 2020 is an example of this thinking.

Engage

Alliances. Differences in cultural and legal approaches, as well as financial resources, will lead to uneven uptake of human augmentation within alliances and this will complicate the challenge of interoperability and integration. Human augmentation technologies will have greater impact if they are adopted across alliances and therefore work must begin now to prepare for their use. Bioinformatics will be vital for understanding how human augmentation could and should be employed and interoperability in this area should, therefore, be a priority. Protocols for sharing sensitive personal information with allies will need to be developed; those that govern the sharing of intelligence could provide a useful template.

New concepts. Thinking about war and how it is fought is unavoidably influenced by the weapons and technology of the time. Some technologies – big guns and machine guns – have changed the character of the battlefield while others – the bomber and the Internet – have expanded our concept of what the 'battlefield' is. Human augmentation will change both. In the next 30 years individual soldiers will create increased and more varied operational effects and this will change how we fight, with implications for our force structure, equipment programme and doctrine. Like the cyber and electromagnetic domain, human augmentation has the potential to blur the boundaries between war and peace, home and abroad, and this will exacerbate the difficulty of attributing acts of aggression and maintaining credible deterrence.

Sustain

Human augmentation will require sustainment: power, software maintenance and upgrades, engineering and medical support will all be needed. These will be interdisciplinary in nature and require specialist skills and equipment. Some human augmentation technologies will be dependent on a highly complex network of suppliers and contractors – and managing them will be a challenge. The supply chain would need to be secure to ensure that those skills would be available at any time to respond to aggressive actions. Sustainment will also need to be delivered in austere, high threat environments. Development of robotics and power-cell technology may mitigate some sustainment challenges but not all of them. Future frontline medical technicians may need to have knowledge of robotics, systems engineering and 3D printing to deliver adequate care to injured personnel. It may not be feasible to deliver this care with only one person, which will change the ratio of enablers to operators and introduce further sustainment challenges.

Direct

Thinking of the person as a platform and taking a human-centric approach to capability development will have significant implications for how Defence is organised. Our current structures are the product of Industrial Age warfare where people were simply the components of units or used to operate platforms. This made it possible to divide personnel, training, equipment, health and management into separate organisational functions. The interdisciplinary nature of human augmentation and the fact that the individual is now a platform will render this approach ineffective and Defence will need to reorganise.

The cognitive load on personnel is likely to increase, particularly for those involved in command and control.[45] Bioinformatics will play a crucial role in identifying commanders and staff with the right aptitude for command and control roles. Brain interfaces, pharmaceuticals and gene therapy could all play a significant part in optimising and enhancing command and control proficiency. In the short term, non-invasive brain interfaces could improve performance by being used to monitor cognitive load, develop better processes and improve training. Virtual and augmented reality could provide commanders and staffs with immersive training linked to analysis and feedback. In the longer term, brain interfaces could network brains within a headquarters providing a completely shared operating picture, improving the quality and speed of decision-making. Brain interfaces could also enable seamless links with artificial intelligence to make sense of complexity whilst still retaining the benefits of innovative and creative human thought.

Future survivability

Russia revealed the Ratnik-3 in 2018, a powered exoskeleton that uses small actuators and motors to reduce the burden of increased body armour. Its 4 hour battery life is a notable constraint but its makers claim it has already been tested in combat.



Erythromer is a nanoscale biosynthetic artificial red blood cell that is stored in powdered form at room temperature and mixed with water when needed. The quest for synthetic blood has been elusive but a chronic worldwide lack of donors is making it increasingly vital. Over 90% of preventable battlefield military deaths are due to haemorrhagic shock; synthetic blood may only last for a short time but long enough to get the patient back to more established medical care. Erythromer is currently undergoing animal testing and may be ready for human trials by 2030.



The world's first remote operation was performed by a Chinese doctor in January 2019. The procedure to remove the liver of the test animal used robotic arms controlled by a doctor over 30 kilometres away over a fifth generation (5G) network. Post-surgery care is equally, if not more, crucial than the surgery itself and much harder to deliver remotely but this is nevertheless an important step forward. This world's first has since been followed up by reports of a successful brain surgery on a human patient.



45 This publication will not discuss command and control in detail as it is covered in Joint Concept Note 2/17, *Future of Command and Control*.

Protect

Human augmentation technologies will also present new opportunities for increased survivability. Exoskeletons would allow personnel to wear heavier armour with less impact on their endurance, speed and manoeuvrability. The treatment of battlefield injuries would be transformed by enabling more sophisticated medical care to be delivered closer to the point of wounding. This could include synthetic powdered blood, optimised for battlefield trauma and stored at room temperature until needed.[46] 3D printed tissue and/or organs could be designed, manufactured and applied further forward in the medical chain with the help of robotically-assisted surgery or surgeons using telemedicine. Each of these technologies is in development now and could be realised in the next 20 years.

Today's rehabilitation tools are likely to be the forerunners of tomorrow's enhancements. Advanced prosthetics to rehabilitate wounded personnel represent the cutting edge of robotics and the latest neurostimulation devices and pharmaceuticals have been successfully used to treat post-traumatic stress disorder (PTSD). Further development of these treatments will not only enable injured personnel to lead the fullest lives possible, it could also pave the way for developing future enhancements. Quicker and more effective rehabilitation will also help Defence organisations hold onto precious and expensive human talent, but policies will need to evolve to support this, such as permitting an amputee to serve in front line roles with the use of a prosthetic.

New vulnerabilities. Bioinformatic data, implants and wearables will create vulnerabilities that could be exploited by malign actors. In a warfighting context, the electromagnetic signature of powered devices such as exoskeletons and brain interfaces could be easily detected. Implanted technologies or data-reliant human augmentation could be hacked or disrupted at a moment of an adversaries choosing. Such vulnerabilities can be mitigated but will require careful consideration throughout the development process and may require operators to learn new skills.

Inform

Intelligence, surveillance, target acquisition and reconnaissance (ISTAR) will continue to be a vital capability.[47] The human-technology interface and the skills of personnel are key weaknesses in today's ISTAR enterprise and human augmentation can play a direct role in improving both. Human augmentation could mean every person is a networked sensor. At the tactical level, data gathered from augmented personnel could identify malign electromagnetic activity or triangulate small arms fire instantly sharing the location of the shooter with the entire network. At a more strategic level, brain interfaces could more effectively link sensors from satellite to eyeball – to provide an enhanced common operating picture.

46 Pan, D., et al., (2016), *Blood*, 'Erythromer (EM), a Nanoscale Bio-Synthetic Artificial Red Cell: Proof of Concept and In Vivo Efficacy Results'.

47 See House of Commons Defence Committee, (2010), *The contribution of ISTAR to operations 2009-10*, for a summary.

Summary

Part 6 has deliberately weighted discussion towards opportunities of human augmentation. The rate at which human augmentation and related technologies develop in the future remains uncertain and there is a tendency to exaggerate the potential. Notwithstanding these cautionary points, the possibilities described in this publication are grounded in today's proven science. Human augmentation is not a panacea, but it will be a critical binding agent that marries the capabilities of machines with the creativity and adaptability of people. It will affect nearly every aspect of society and, in turn, the way in which Defence protects and furthers national interests. Successfully exploiting human augmentation will require Defence, and society, to face up to uncomfortable ethical and legal dilemmas. So far, Defence organisations in liberal democracies have adopted a 'wait and see' approach, choosing to let ethical debate and technical developments play out. This passive stance will cede momentum to our adversaries and cause Defence to miss opportunities to improve the well-being and effectiveness of our Armed Forces.

Human augmentation possible benefits for Service personnel



Physical performance

- Increased strength, speed and endurance
- Enhanced sensory functions and range

Psychological performance

- Improved attention, vigilance and memory
- Increased perception and situational awareness
- Enhanced decision-making
- More efficient learning

Social performance

- Improved communication
- Better group cohesion – stronger units

Health and combat readiness

- Improved health and well-being
- Fast recovery from injuries and wounds
- Enhanced resilience and perseverance

> "At the core of future military advantage will be effective integration of humans, artificial intelligence and robotics into warfighting systems – human-machine teams – that exploit the capabilities of people and technologies to outperform our opponents.
>
> Joint Concept Note 1/18, *Human-Machine Teaming*

Key deductions and insights

- Human augmentation provides an insight of what lies beyond the Information Age – the coming of the Biotech Age, where focus on the human platform will grow to match that of the machine. This will require Defence to organise around a human-centric approach.

- Human augmentation is bringing about a securitisation of the life sciences which will necessitate a more sophisticated relationship between the public and private sector.

- Differences in national, cultural and legal approaches will lead to an uneven uptake of human augmentation within international alliances. Early and close cooperation with allies will be required to realise the benefits of human augmentation and to understand how and where coalitions can develop interoperability and deconflict.

- Human augmentation will change the character of war and may lead to fundamentally new concepts.

- Human augmentation will require entirely new classes of personnel, training regimes and deployment protocols in the Defence arena.

- Human augmentation will play a key role in reducing cognitive load and enabling all levels of command to succeed in an increasingly complex, congested and fluid future operating environment.

- Increased survivability will be a key benefit of human augmentation, enabling our people to be more resilient to hostile environments and enemy action. Our ability to treat injuries and save lives closer to the point of wounding will dramatically increase in the next 10-20 years.

- Today's rehabilitation tools, such as prosthetics and neurostimulation, will be the technologies used in tomorrow's enhancement. Defence should focus on these therapeutic efforts as a pathfinder to future opportunities.

- Human augmentation will create new and potentially more critical vulnerabilities that must be considered from the outset of their development.

- Human augmentation will make a critical contribution to the ISTAR process by improving the interface between sensor, processing and dissemination.



Annex A

Project methodology

This annex sets out the method used in producing *Human Augmentation – The Dawn of a New Paradigm*. It is hoped that by setting out the methodology of this strategic implications project readers can understand how the conclusions in Parts 1 to 6 were reached. It is also hoped that readers will learn from this method and identify insights that can improve their own work.

Scenario creation

The first step in this project was creating suitable scenarios. The scenarios needed to generate defence and security insights and cover the technological possibilities as far as possible. To ensure the scenarios considered all aspects they also needed to cover social, economic, political, ethical and individual aspects. In keeping with the strategic analysis programme the time horizon was 30 years in the future – 2050. In addition to representing plausible futures, the scenarios provided the starting point for deriving implications with a strategic, security and defence focus.

Scenario analysis

Scenario analysis is a useful method to identify the multiple ways the future might evolve. This technique can help decision-makers develop plans to exploit opportunities, reduce uncertainties and manage future risks. Additionally, monitoring the indicators embedded in various scenarios can create early warning signals of likely future trajectories. Scenario analysis is most useful when a situation is complex or single predictions are too uncertain to trust – this human augmentation project is just such a situation.

If used in the initial stages of policy formulation or when developing long-term corporate strategies, scenario analysis can have a significant impact on decision-making. The method provides a set of plausible and possible futures for which decision-makers should consider. It is also useful as a tool for confronting decision-makers and stakeholders with alternative futures which they should make plans for. Engaging stakeholders and decision-makers in the scenario analysis process can generate commitment for the projects, save time and produce more useable results.

Scenario creation can be subdivided into different phases, including:

- investigation (for example, horizon scanning);
- analysis (for example, driver identification, uncertainty analysis and cross-impact analysis);
- projection (for example, scenario writing);
- implications (for example, back casting and SWOT (strengths, weaknesses, opportunities and threats) analysis);

- communication (for example, trend reporting); and
- monitoring (for example, trend monitoring).

All the scenarios in this project used the first four phases.

Using scenarios offers the possibility to describe many different possible and plausible futures. Comparing multiple scenarios in the analysis phase makes it easy to identify factors or drivers that are essential for future developments, whether desired or not. In addition, scenario analysis can be used to test assumptions about the future or even find and warn against critical developments.

A very important advantage of scenario analysis is the possible involvement of decision-makers and stakeholders in the scenario process. This promotes a high level of understanding for the various possible future developments and achieves a high commitment to the actual work.

Investigation and analysis

The first step towards creating the human augmentation-related scenarios was to acquire the basic factors – called influence factors. Workshops were held in which human augmentation-related ideas were written on 'sticky notes' and clustered into factors according to perceived commonality. The outcome of this process was a large number of initial factors that varied in nature and scope. These factors were not necessarily independent, and in some cases had multiple, different meanings. An example is the economy factor which originally referred to both revenue and cost, the former being a driver and the latter a consequence. Potential relationships were identified using an approach inspired by systems engineering[48] and used the doctrine, organisation, training, materiel, leadership and education, personnel, and facilities (DOTMLPF)[49] framework to analyse the initial factors.

Human augmentation framework

The analysis showed that the factors could be grouped in to five major blocks of factors: drivers/incentive; prerequisites; enablers/disablers (composed of three components: frameworks, views and regulators); disruptors; and possibilities/risks. These blocks represent: the drivers for human augmentation (why it is needed/wanted); the prerequisites for its development (including those factors that may hinder development); the enablers/disablers (structures needed for its realisation); unknown events that may occur (disruptors, possibilities and risks) along the way; and, finally, the outcome (the realisation of human augmentation). The grouping provided a structure to show how the various factors were linked. The relationships at the higher level have a temporal component and can be understood as a regulatory process that works (primarily) in a sequential manner.

48 ISO 21500 guidance on project management is an international standard developed by the International Organization for Standardization.

49 This framework is used by the United States Department of Defense and is defined in The Joint Capabilities Integration Development System.

A detailed framework was developed based upon the blocks (see Figures A.1 to A.6) using the initial factors and their content. The framework was used to identify additional factors of potential interest for human augmentation, (such as factors that did not emerge during the workshops). The final **influence factors** used in the scenario generation process were extracted from this framework.

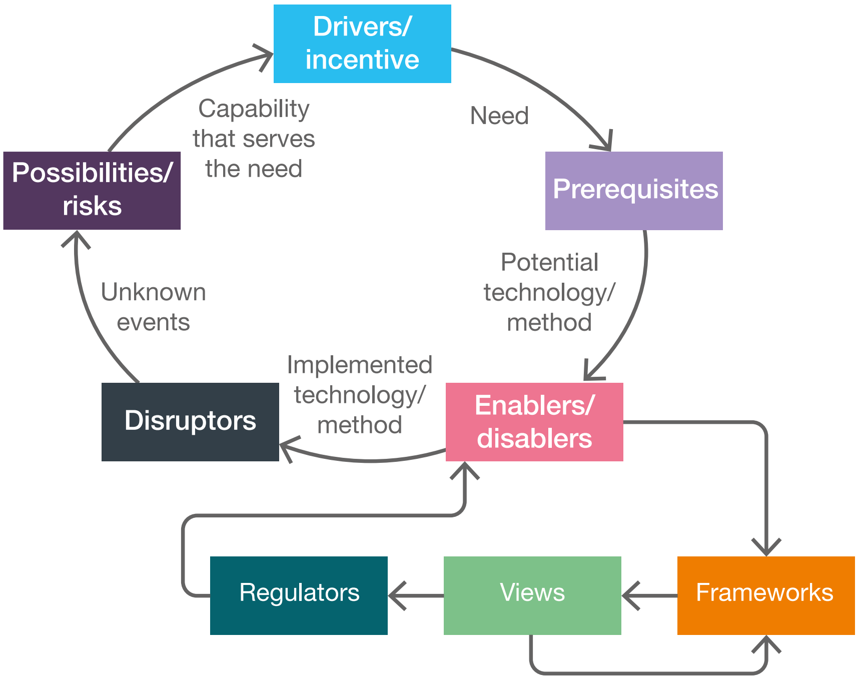


Figure A.1 – Overview of the relationships between blocks (and components)

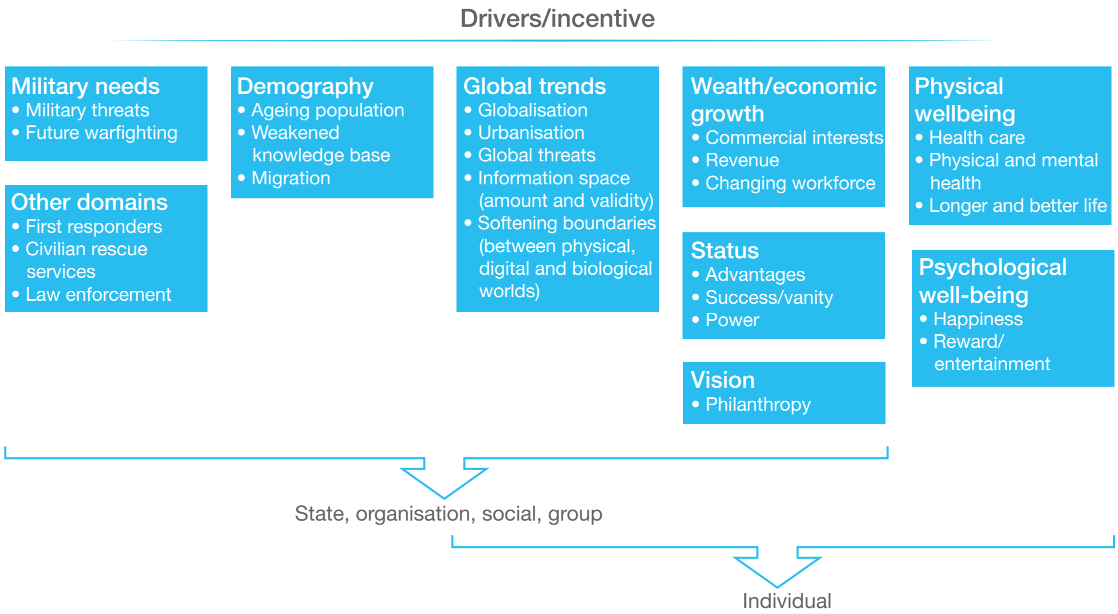


Figure A.2 – Content of block drivers/incentive

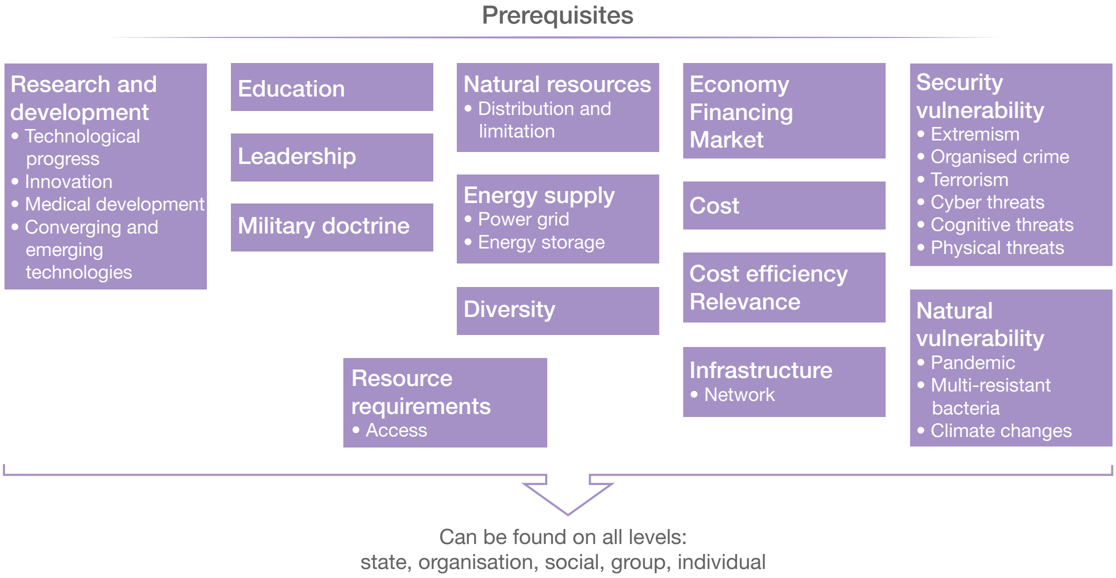


Figure A.3 – Content of block prerequisites

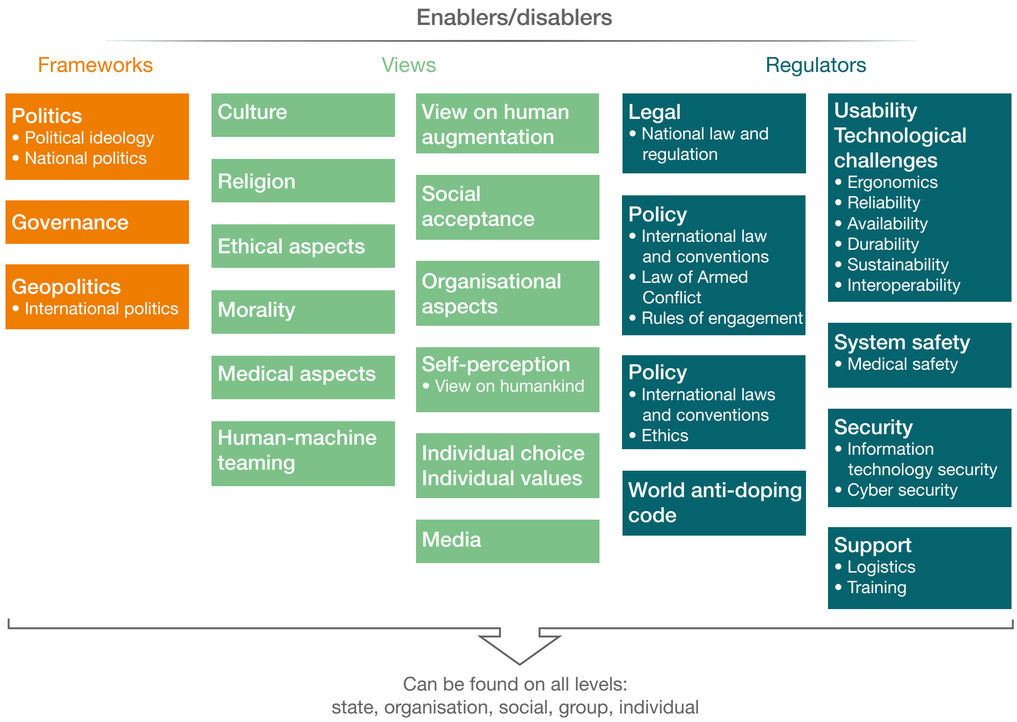


Figure A.4 – Content of block enablers/disablers

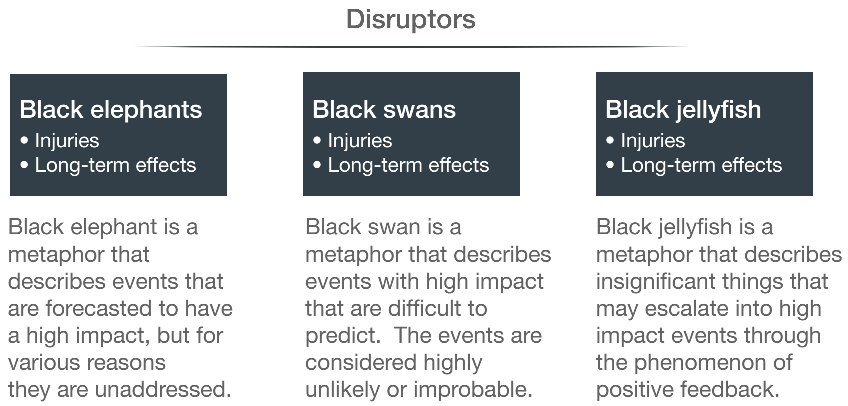


Figure A.5 – Content of block disruptors

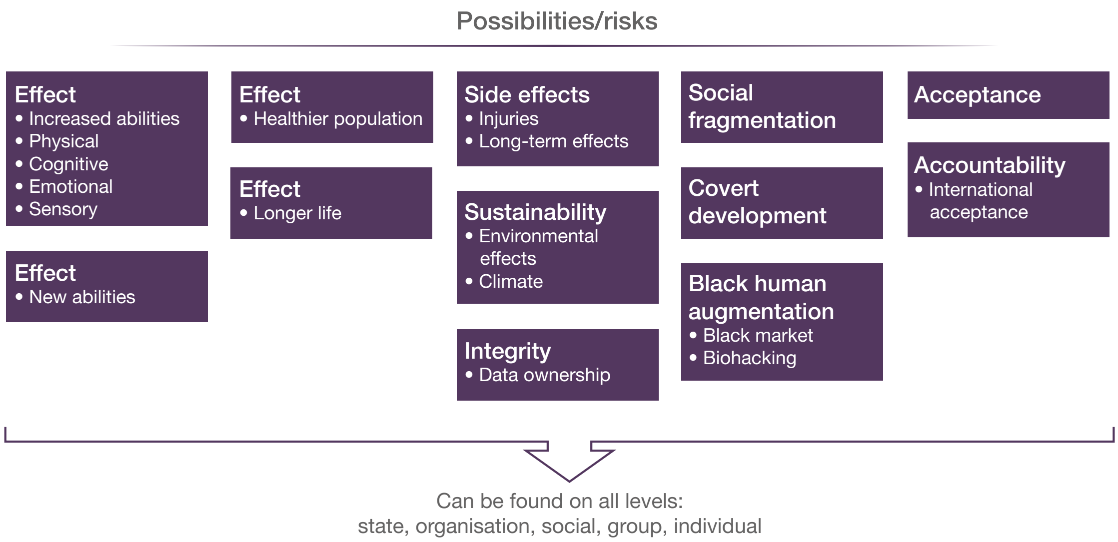


Figure A.6 – Content of block possibilities/risks

Influence factors

There were 35 influencing factors identified and these are listed in Table A.1. The criteria for being selected as influencing factors were their relevance to (military) strategic implications and influence on the strategic context: social, technological, political and economic aspects.

Influence factors									
1	Military needs	8	Security vulnerability	15	Technological challenges – physics	22	National laws and regulation	29	First responders/ civilian rescue services
2	Social drivers	9	Natural vulnerability	16	National politics	23	International laws and regulations	30	Diversity
3	Commercial interests	10	Research and development	17	Governance	24	System safety	31	Physical capabilities
4	Health care	11	Resources	18	Geopolitics	25	Security (information technology and cyber)	32	Cognitive capabilities
5	Well-being	12	Cost	19	Culture	26	Support	33	Emotional capabilities
6	Demography	13	Acceptance	20	Religion	27	Individual drivers	34	Senses
7	Technological progress	14	Technological challenges – energy	21	Ethics	28	Financing	35	Morality

Table A.1 – Influence factors

Key factors

In the second step, the influence factors were subjected to a cross-impact analysis to identify the important drivers. The process distilled the influence factors down to 14 **key factors** (these can be found in Figure A.7 below). The definitions of the key factors were sharpened during this process and four to six projections were made to each key factor. Each projection explored how a key factor could develop in a given direction over a 30-year time horizon. This important step requires good knowledge in the respective specialist area and enough creativity to allow an exploration of the unknown. The projections form the backbone of the scenarios that have been developed.

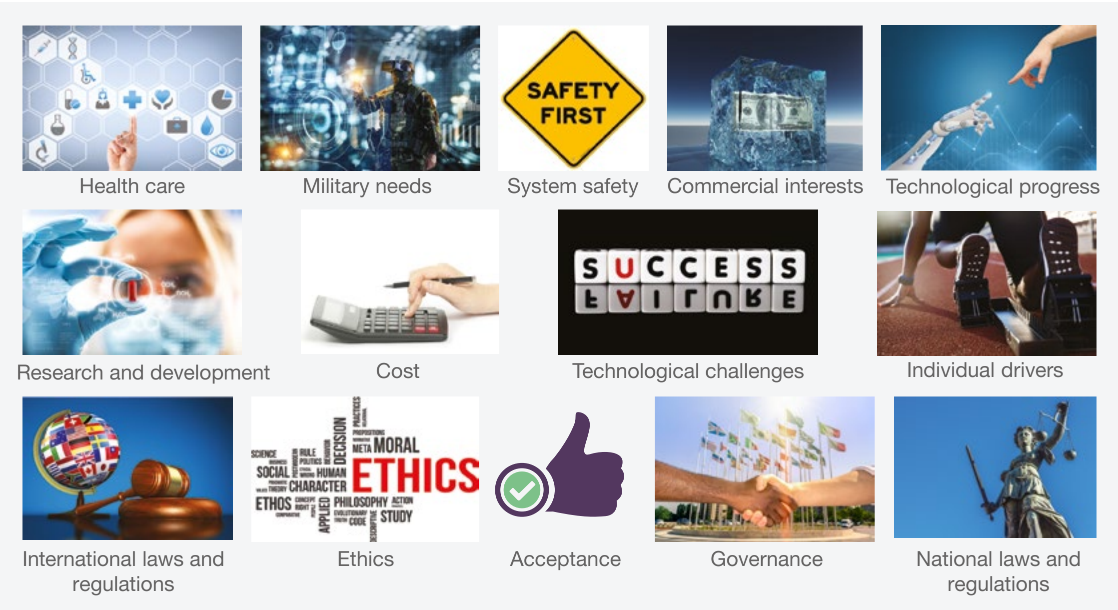


Figure A.7 – The 14 key factors

Projection and scenarios

Due to the high number of key factors and the complexity of the scenarios a calculation based on a consistency matrix[50] with subsequent clustering was performed. The risk assessment and horizon scanning (RAHS) software, an in-house product of the future analysis branch of the Bundeswehr Office for Defence Planning was used to conduct this analysis. The calculation ensured that all the resulting raw (or initial) scenarios were consistent (that is, free of contradiction). Each raw scenario is produced by using one key factor projection. These raw scenarios were then grouped using a clustering method similar to the one used to combine initial factors into blocks.[51] The percentage of the relevant projection per key factor was calculated. For example, Table A.2 shows the proportions (expressed as a percentage) of the projection used (from the respective key factor) which were combined to produce the scenario 'globalised world, national tensions'.

Key factor	Projection	%
Health care	1A – Robocop through health care system	0
	1B – Elysium	64
	1C – Universal soldier	36
	1D – Basar of Kyrion (Valerian)	0
Military needs	2A – Arms race	90
	2B – Effective control	0
	2C – Rogue nations	0
	2D – Human performance enhancement mercenaries	10
Commercial interest	3A – Market run	0
	3B – Niche market	100
	3C – Regulated market	0
	3D – No market at all	0
System safety	4A – All inclusive safety	3
	4B – Almost safe	72
	4C – Almost safe with side effects	10
	4D – At least no side effects	7
	4E – Kamikaze safety	4
	4F – Unsafe	4

Table A.2 – Section of the scenario cluster that became the 'globalised world, national tensions' scenario

50 The consistency matrices were filled in by several people from all participating nations in parallel and then consolidated. This approach should ensure that the previously mentioned limitations of the method have been kept as low as possible.

51 By selecting certain parameters, the analyst has an influence on how many scenario clusters are created during clustering. Experience is important to determine an optimal number of scenario clusters without loss of information.

From these raw scenarios the seven that were most relevant to the strategic implications project were further developed. The seven selected scenarios were brought to life in a one-week workshop using a variety of creative methods, providing each scenario with a narrative and an origin story. Figure A.8 gives an overview of the seven scenarios.

The seven scenarios span a broad future space and covered a whole range of possible futures, from the perfect utopia to the disastrous dystopia. Four scenarios (highlighted in colour in Figure A.8) were identified as being of most interest for military and future warfighting aspects. Below is a short summary of each of the four scenarios we used in the next step in the analysis – implications.



1. From high hopes to great concerns
2. Dark clouds in the evolution of human enhancement
3. The winner takes it all
4. Globalised world, national tensions
5. Human performance enhancement catastrophe
6. Human performance enhancement utopia
7. Competitive arms race

Figure A.8 – The seven scenarios

Scenario – From high hopes to great concerns

The promise of human augmentation to increase the quality of life was at first accepted with great enthusiasm around the world. After a short time, however, human augmentation technologies, although highly effective, were found to be unsafe or had side effects or withdrawal symptoms – some of them serious. Companies still invested in research and development of human augmentation technology but increasingly vocal opposition groups started to raise their concerns about the technologies and their practitioners. In the late 2030s the world divided. One part of the world, the West, followed a path that prohibited all invasive human augmentation technologies. People with existing human augmentation technologies were required to be registered by a newly formed state agency, had a lower social status and could not run for public office.

A black market for maintenance and new products, mainly from the East and Africa emerged. Only military, law enforcement and security organisations could continue to use invasive enhancements. Careers in these organisations became unpopular.

The other part of the world, the East, still allowed human augmentation technology, but the market was highly regulated (for example, age limits). To overcome the known side effects, a combination of different human augmentation technologies were used. Human augmentation business was market driven and research and development happened in private corporations. Africa/Nigeria became a test ground for new human augmentation technology. Special human augmentation technologies were developed for law enforcement and the military, for example, the development of super soldiers.

Scenario – Dark clouds in the evolution of human enhancement

Disruptive steps in human augmentation technologies during the last decades have led to a situation where human performance enhancement is cheap, safe and practically available to all. Human augmentation is considered highly acceptable and seen as natural step in human evolution. Companies and nations are cooperating globally and invest heavily into human augmentation development. The adoption and development of human augmentation technologies was characterised by three major technological steps that happened in parallel in both the West and in the East from 2020 until today. The first disruptive step was the development of enhanced DNA modification technology in around 2035 which led to increased investment in research and development and growth in the human augmentation market. The second disruptive step, which occurred around 2040 was related to the development in artificial intelligence. The third disruptive step around 2045, saw the development of, what was in effect, a universal vaccine for all diseases. This led to global acceptance of human augmentation.

However, even though human augmentation was a global success story, tension between the East and West endures. The United States remains the leading western nation, both politically and technologically, and it leads on developing safety, usability and software solutions for human augmentation. China is the leading eastern nation and leads the way in developing components and solutions for robotics related to human augmentation.

Scenario – Globalised world, national tensions

A global understanding prevails between nations. Nations thrive and prosper, and high-technology human enhancements are shared between nations. Inside different nations, however, things were not as good as they seemed. The gap between normal citizens and the elite grew larger than ever before. Between 2020 and 2030, a genetically modified virus was released into the world, infecting and killing billions before it could be isolated and controlled. The virus still exists and still infects people. The only way to survive the infection is through the use of human augmentation technology. Ironically, the virus that was designed to wipe out humanity led to widespread human enhancement.

Nevertheless, human augmentation technology is very expensive and it is created and controlled by private organisations beyond the reach and control of the governments. People are still dying from the virus because they are too poor to afford the cure. There was an insurgency were people tried to topple the existing government in an attempt to prevent further deaths amongst the poor. However, the insurgents were overpowered by an enhanced military, although a resistance endures.

Scenario – Competitive arms race

After a long period of nationalism, isolationism and proliferation states eventually agreed to cooperate and end isolation for reasons of (economic) growth and scientific and intellectual development.

In 2050, human augmentation is mature; the technologies are perfected and highly accessible at low cost. Human augmentation is effective, safe and totally accepted. Some types of interventions are state sponsored, through 'life care accessible for all' programmes, while others are kept secret and are limited to military use only. 'Democratic states' perceive human augmentation as critical to economic development. There is a free, deregulated and competitive market. Human augmentation health care is available for all, and the crossover from civilian into military applications has resulted in lower costs for the military since the basic technology is proven.

A class of warrior, remnants of nationalist times, remains and so does the antagonism that has built up between military and civilian society. The risk of new conflicts is omnipresent, and the power of states has been eroded due to their inability to work in large coalitions.

Implications

Identifying implications is one of the most important, but also most difficult, steps in strategic foresight. Each future scenario is linked to the present via its own development path, but what lessons, what deductions can be made from the future scenarios for decision-makers?

SWOT (strengths, weaknesses, opportunities and threats) analysis[52] as decision support was the method of choice in this project. The strengths and weaknesses relate to the organisation itself, whereas the opportunities and threats relate to the external environment and in this case to the future developments regarding human augmentation.

SWOT analysis is simple, easy and are widely used today. But like any other method, it has its limitations. It is focused on only one goal, without considering the costs and benefits of alternative means of achieving the same goal. This is not a problem so long as the analyst is aware that the results are only a part of the options for the decision in question. In this project, SWOT analyses were carried out several times with the same or slightly modified questions, and with different participants, so that different approaches to achieving the same goal were considered. Once the SWOT analysis was completed the results were consolidated.

The SWOT analysis always followed the same pattern. The first and most important step for the participants was to immerse themselves in the corresponding scenario and to imagine that this scenario had occurred. To support the process, participants had to decide which aspects of this scenario were desirable and which were alarming. Based on the key question 'What opportunities and threats for Finland, Germany, Sweden and UK security policies arise from the scenarios?' The opportunities and threats for the security policy of the respective country were worked out for each scenario and recorded in tabular form. These findings were then translated back into findings relevant to the present, by asking the question 'What would be the strengths and weaknesses of Finland,

52 SWOT (strengths, weaknesses, opportunities and threats) analysis was developed in the 1960s for position determination and strategy development in companies.

Germany, Sweden and UK security policies in dealing with these scenarios?' These results were also recorded in tabular form. Figure A.9 shows a way to visualise the SWOT quadrant and the four questions presented.

1. How do you use the strengths to take advantage of the opportunities?
2. How can you work on the weaknesses to seize the opportunities?
3. How do you use the strengths to manage the threats?
4. How can you work on the weaknesses to master the threats?



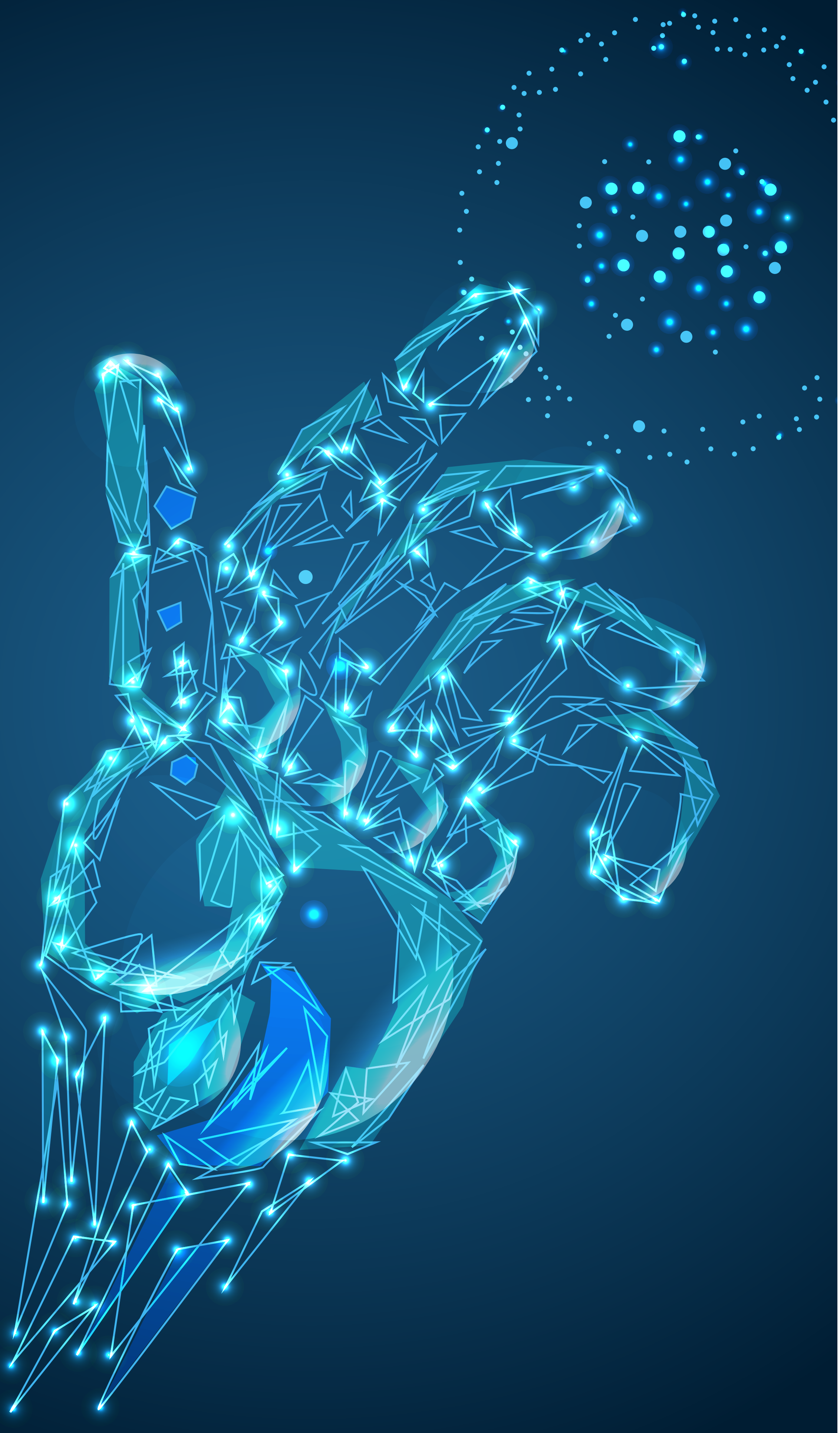
Figure A.9 – Template of a SWOT portfolio

The final, concluding step of this analysis is strategy development. This is done independently by the respective nation. For this step, it is advisable to expand the group of participants again and to include the future decision-makers. This increases the understanding of the scenarios and the topic itself and creates a commitment to the project and its recommendations.

The combinations from the SWOT portfolio served as the basis for strategy development, and the practical steps that follow in turning strategy into action. It is interesting to note that different groups of participants often came up with similar actions, tasks and options. A recommended next step is working out similarities and differences between strategic recommendations, with a focus on 'future-robust' options.

Communication and monitoring

The participating nations will use the gained insights and knowledge as a foundation for establishing national human augmentation policies regarding use and research and development. International cooperation will continue to be one of the most important factors to understand and control the potential of human augmentation. The Multinational Capability Development Campaign (MCDC) is currently running a project on human augmentation focused on cooperation and interoperability where the author Nations participate.



Annex B

Technology review

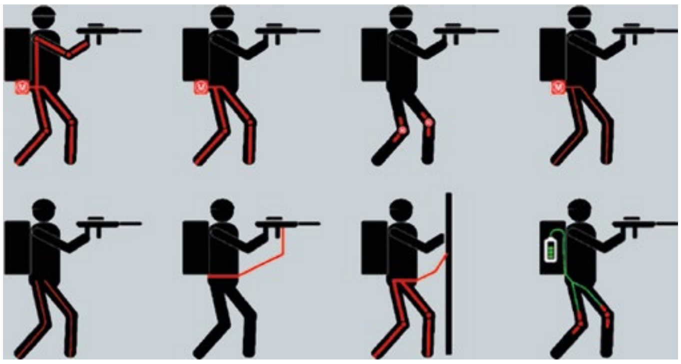
According to the transhumanistic thinking model, the human is an incomplete creature that can be shaped in the desired direction by making responsible use of science, technology and other rational means.[53]

Part 2 provided a simple overview of human augmentation technologies; to simplify the publication, technologies were presented individually. In this annex, the technologies are described in more detail using a different context. The technologies are discussed using the three performance categories: physical, psychological and social. It is hoped that this annex will provide the reader with a better understanding of the complex interplay of the various technologies between each other and in different augmentation situations. It shows which technologies are already in widespread use and describes expected future developments.

Section 1 – Physical augmentation

Physical augmentation includes improvements to strength, speed, dexterity and stamina. The exoskeleton, an external structure that supports the musculoskeletal system, is an example. Other options include use of substances, for instance, anabolic drugs are a known performance enhancer allowing individuals to train more efficiently, ultimately to exceed their physical potential.

Exoskeletons



An exoskeleton is an external, removable structure capable of supporting the human musculoskeletal system. The goal is to increase strength and load carrying capability, improve endurance, as well as preventing injuries. The exoskeleton can be combined with body armour for increased protection. Exoskeletons can be categorised as powered or passive (unpowered), if the frame is hard or soft, and whether or not it covers the full body. Another category is energy scavenging exoskeletons that use the movements of the body to harvest energy and recharge batteries. A light version of the full body system is the lower extremity exoskeleton aiming at reducing the loads on the knees as well as energy consumption during walking and running. There has been significant interest in exoskeletons, mainly for therapy and mobility rather than augmentation, but with some explicit military applications intended to reduce fatigue

53 Bostrom, N., (2003), *The Journal of Value Inquiry*, 'Human genetic enhancements: a transhumanist perspective'.

and increase strength.[54] The mechanics of the exoskeleton must cooperate with the biomechanics of the human body allowing and enforcing the motions of the joints in the musculoskeletal system. Potential limitations include constraints on speed and range of movement, obstructed access to confined spaces as well as dependency on energy supplies and connectivity. A related technology is the robotic glove capable of providing additional grip strength. The purpose of the glove is to reduce injuries caused by muscle strain as well as reducing fatigue when performing repetitive tasks.[55]

Exoskeletons could be playing a role on the battlefield by 2030. Some might be designed to prevent injuries by, for example, taking the strain of heavy loads or by absorbing shocks for those working on board ships or other vehicles. It is less clear that powered systems will be widely used, although they could be used for situations that only require movement over short distances but need heavy protection. For example, breaching or explosive ordinance disposal tasks. For powered exoskeletons to conduct a wider range of military tasks they will need a suitably light, durable and compact source of power to give them sufficient range; presently this looks difficult to achieve.

Potential and issues. By 2040 artificial intelligence might be capable of improving the interaction between the user and exoskeleton so that they move 'as one'. Looking even further into the future, systems could be controlled at will using electrodes in the brain. This would mean that using an exoskeleton would require training and practice with it before it could be used, but its effectiveness would be greater. The risk of not exploring the potential of exoskeletons is that the opponent will acquire the technology first: increasing their lethality, mobility and protection.

Substances

Substances are likely to continue to be used to enhance physical performance. For example, anabolic androgenic steroids have similar effects on muscle growth as naturally occurring testosterone and are mainly used to stimulate muscle growth or to treat wasting conditions.[56] Another well-known substance is creatine which can have a positive effect on performance during exercise. Studies have shown that taking creatine appears to increase power and reduce fatigue but also increases the risk of being overweight and injury.[57] Erythropoietin (EPO) is a hormone produced mainly by the kidneys and has been synthesised as medicine for anaemic diseases, but has also been used, illegally, to enhance performance in sport.[58]

54 Onose, G., et al., (2016), *Frontiers in neuroscience*, 'Mechatronic wearable exoskeletons for bionic bipedal standing and walking: a new synthetic approach'.

55 An example of a robotic glove can be found at https://www.bioservo.com/professional/ironhand.

56 Sullivan, M. L., et al., (1998), *Progress in cardiovascular diseases*, 'The cardiac toxicity of anabolic steroids'. Also Orr, R. and Singh, M. F., (2004), *Drugs*, 'The anabolic androgenic steroid oxandrolone in the treatment of wasting and catabolic disorders'.

57 Branch, J. D., (2003), *International Journal of Sport Nutrition and Exercise Metabolism*, 'Effect of creatine supplementation on body composition and performance: a meta-analysis'. Rawson, E. S., et al., (2011), *Nutrition*, 'Low-dose creatine supplementation enhances fatigue resistance in the absence of weight gain'.

58 Atkinson, T. S. and Kahn, M. J., (2020), *Blood Reviews*, 'Blood doping: Then and now. A narrative review of the history, science and efficacy of blood doping in elite sport'.

Potential and issues. Although anabolic steroids promote muscle growth, it does come with a variety of side effects, including many that are unpleasant, and some that are lethal.[59] A benefit of creatine is that there are, generally, no serious side effects. EPO does increase the capacity of the blood to carry oxygen and performance gains can be impressive, but the side effects can be serious, including blood clotting which can lead to a stroke and even death.[60]

Section 2 – Psychological augmentation

Psychological augmentation consists of improvements to cognitive, emotional, motivational as well as sensory functions. Cognitive augmentation aims to improve mental faculties including memory, attention, alertness, creativity, understanding, decision-making, intelligence and vigilance. The goal of emotional augmentation is to increase well-being and control over emotional states while motivational augmentation works towards drive and focus. Psychological augmentation is historically, and commonly, associated with various types of substances and therapies. Emerging technologies in this area include brain interfaces, neurostimulation and sensory modification.

Substances

Cognition enhancing drugs (also called smart drugs or nootropics) range from caffeine, nicotine and various herbal supplements to stimulants such as amphetamines, methylphenidate and modafinil, but also anti-dementia drugs that may improve long-term memory.[61] Beta-blocker drugs can calm people, which has been used to both improve performance by reducing stage fright, but also enhance memory consolidation, a phenomena which could be used for post-traumatic stress disorder (PTSD). Other types of cognitive augmentation include modulation of blood glucose and hormones, such as adrenaline and testosterone. Psychedelic drugs, such as lysergic acid diethylamide (LSD) and methylenedioxymethamphetamine (MDMA), commonly known as ecstasy or molly, have seen a renaissance in recent years for therapeutic applications.[62]

Herbs such as Rhodiola rosea, through its fatigue-reducing properties, has a notable positive effect on cognition.[63] Studies on the herb Ginko biloba has shown that it has the ability to reduce cognitive decline and improve memory in the elderly.[64] Apart from herbs and synthetic drugs, supplements in the form of amino acids have the potential to enhance cognitive abilities. D-serine has shown promise of increasing cognitive

59 Kuhn, C. M., (2002), *Recent Progress in Hormone Research*, 'Anabolic steroids'.

60 Atkinson, T. S. and Kahn, M. J., (2020), *Blood Reviews*, 'Blood doping: Then and now. A narrative review of the history, science and efficacy of blood doping in elite sport'.

61 Franke, A. G., et al., (2014), *European archives of psychiatry and clinical neuroscience*, 'Substances used and prevalence rates of pharmacological cognitive enhancement among healthy subjects'.

62 Nutt, D., (2019), *Dialogues in Clinical Neuroscience*, 'Psychedelic drugs-a new era in psychiatry?'.

63 Spasov, A. A., et al., (2000), *Phytomedicine*, 'A double-blind, placebo-controlled pilot study of the stimulating and adaptogenic effect of Rhodiola rosea SHR-5 extract on the fatigue of students caused by stress during an examination period with a repeated low-dose regimen'.

64 Santos, R. F., et al., (2003), *Pharmacopsychiatry*, 'Cognitive performance, SPECT, and blood viscosity in elderly non-demented people using Ginkgo biloba'.

functions.[65] Similarly, L-tyrosine has shown positive effects on cognition during acute stress.[66]

Cognition enhancing drugs typically affect simple, low-level functions such as alertness and memory rather than top-level functions such as intelligence. They change brain states, sometimes in complex ways, but do not add any new information to the system. In general, they function best when managing trade-offs between different cognitive styles such as broad to focused attention.[67] The effects have so far been modest, though there is also some evidence they may benefit low functioning individuals but impede high functioning ones.[68] They can also involve trade-offs between different functions, for example, attention and creativity or reaction speed and mental flexibility.[69] Augmentation of low-level cognitive abilities is likely to be useful when applied well but this is likely to be difficult, since the therapeutic and enhancing effects can act in the short or long term, making dosage and effect somewhat unpredictable. Some substances may also have unknown interaction effects, lead to addiction and changes in tolerance.

Nevertheless, drugs and supplements can provide a convenient platform for various forms of augmentation and their effectiveness may be further enhanced in the future. By combining them with biotechnology and nanotechnology, or advanced machine learning for optimisation and individualisation, significant improvements can be expected. Micro-dosing of psychedelic and other drugs could also be used to improve creativity and out of the box thinking.[70]

Emotional enhancement

Emotional enhancement is a wide field, including well-being, control over emotions, social bonding and different kinds of affection. As current therapeutic and recreational drug use indicates these effects are tremendously important to individuals and society but also relatively poorly understood. While emotional enhancement may sound relatively unimportant, even trivial, the effects on the individual can be profound.[71]

There has been significant interest in understanding how the modulation of the oxytocin system can enhance perception of social cues and emotional expression, positive

65 Levin, R., et al., (2015), *Journal of Psychiatric Research*, 'Behavioral and cognitive effects of the N-methyl-D-aspartate receptor co-agonist D-serine in healthy humans: initial findings'.

66 Banderet, L. E. and Lieberman, H. R., (1989), *Brain Research Bulletin*, 'Treatment with tyrosine, a neurotransmitter precursor, reduces environmental stress in humans'.

67 Bostrom, N. and Sandberg, A., (2009), *Human Enhancement*, 'The wisdom of nature: an evolutionary heuristic for human enhancement'.

68 Muller, U., et al., (2004), *Psychopharmacology*, 'Effects of modafinil on working memory processes in humans'.

69 Mohamed, A., (2014), *The Journal of Creative Behavior*, 'The Effects of Modafinil on Convergent and Divergent Thinking of Creativity: A Randomized Controlled Trial'.

70 Anderson, T., et al., (2019), P*sychopharmacology*, 'Microdosing psychedelics: personality, mental health, and creativity differences in microdosers'.

71 Kahane, G., (2011), *Enhancing Human Capacities*, 'Reasons to feel, reasons to take pills'.

communication trust, interpersonal synchrony and coordination, and prosocial behaviour.[72] Understanding of the neural underpinnings of various forms of sexual and romantic emotions is increasing, and there is significant interest in studying and applying these findings. While manipulation of libido will be achievable, if not now, then relatively soon, strengthening of pair-bond emotions is further away, but it also appears feasible.[73]

Motivation enhancement

Motivation enhancement aims to increase drive and focus and is a major goal of smart drugs. Motivation enhancement is relatively well understood in its simplest forms (for example, stimulants). The main forms of motivation enhancement are likely to be modulation of the arousal and dopaminergic systems, today typically done using stimulant drugs. Attention is linked to the cholinergic system. At present the neuroscience of boredom is only partially understood but might become amenable to control.[74] Some cognition enhancing drugs also have motivational effects (especially stimulants), driving users to perform well.

It might be possible to fine-tune motivation in other ways, for example, by having software steer attention towards relevant stimuli or implement conditioning to reward/discourage actions or thoughts. Managing boredom, attention and drive are important in many situations. Like cognitive augmentation the prosocial and workaholic applications avoid the stigma of recreational drugs that may hold back other forms of emotional enhancement.

Potential and issues. Substances often rely on metabolism to trigger the intended outcome. This involves several steps of biotransformation as the substance is converted into the active ingredient. This can result in unintended outcomes. For example, when intended muscle gain is accompanied by emotional instability. Drugs can be prepared using nanomaterials to release the active ingredient in the exact location intended, better controlling the drugs effect. It has, however, been difficult to find suitable nanomaterials and some of those that at first appear to be suitable have been found to be poisonous.[75] Enhancing feelings of trust and empathy is likely to be important and much depends on the application; both increasing and decreasing conformity could be desirable (for the person or the group) depending on the situation (for example, avoiding groupthink or rapidly building teams – or propaganda). Developing emotional enhancements will depend on breakthroughs in neuropsychology and addressing the resulting ethical dilemmas. Over past decades, despite massive effort, anti-depressive therapy has progressed at only a modest pace.

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72 Schulze, L., et al., (2011), *Psychoneuroendocrinology*, 'Oxytocin increases recognition of masked emotional faces'; Ditzen, B., et al., (2009), *Biological Psychiatry*, 'Intranasal oxytocin increases positive communication and reduces cortisol levels during couple conflict'; Kosfeld, M., et al., (2005), *Nature*, Oxytocin increases trust in humans'; Arueti, M., et al., (2013), *Journal of Cognitive Neuroscience*, 'When two become one: the role of oxytocin in interpersonal coordination and cooperation'; and Striepens, N., et al., (2011), *Frontiers in Neuroendocrinology*, 'Prosocial effects of oxytocin and clinical evidence for its therapeutic potential'.

73 Savulescu, J. and Sandberg, A., (2008), *Neuroethics*, 'Neuroenhancement of love and marriage: The chemicals between us'.

74 Merrifield, C., (2014), University of Waterloo, 'Toward a Model of Boredom: Investigating the Psychophysiological, Cognitive, and Neural Correlates of Boredom'.

75 Bostrom, N. and Sandberg, A., (2009), *Science and Engineering Ethics*, 'Cognitive Enhancement: Methods, Ethics, Regulatory Challenges'.

Boosting willpower and self-control will make long-term goals dominate over short-term ones and 'motivation on tap' could make education, training and work more effective (although with the attendant risks of abuse).[76] Controlling boredom is likely to be closely tied to controlling attention, and could have big impacts on vigilance, performance and mental flexibility.

Neurostimulation and brain interfaces



Neurostimulation uses electronic devices to stimulate nerve cells in the brain and includes invasive and non-invasive brain stimulation methods. Transcranial magnetic stimulation uses magnetic fields to stimulate nerve cells in selected areas of the brain, and transcranial electric stimulation applies small electrical currents to the brain using electrodes. Stimulation has been able to improve the results of motor training and numerical observation. Transcranial electric stimulation has improved the performance of image analysts in identifying targets.[77] Using transcranial stimulation to synchronise rhythmic brain circuits has been shown to improve working memory in older adults.[78] Transcranial pulsed electromagnetic fields has been effective in treating severe depression.[79] Another type of electrical stimulation could be used to alleviate virtual reality sickness symptoms.[80]

Potential and issues. Electric stimulation of the brain has been used to relieve pain, treat damaged vision, improve data processing, and enhance learning of languages.[81] These types of brain stimulation methods are, however, only likely to have modest effects. Although they have been used to improve cognitive functions, their main use is likely to be in the treatment of mental/neurological conditions. Side effects range from discomfort to seizures and memory loss while the long-term effects are still unknown. This technology is relatively lightly regulated and there is a significant community interested in DIY neurostimulation.

Brain interfaces

Brain interfaces include brain-computer interfaces and brain-brain interfaces, and they are based on the interpretation of brain signals that are measured from the surface of the scull, or in future, directly from brains. The electroencephalography-cap is an example of an external neural interface while implants such as electrodes for deep brain stimulation represent internal neural interfaces. Brain interfaces enable communication between brain

76 Magen, E., et al., (2014), *Proceedings of the National Academy of Sciences*, 'Behavioral and neural correlates of increased self-control in the absence of increased willpower'.

77 Mckinley, R. A., et al., (2013), *Behavioral Neuroscience*, 'Acceleration of Image Analyst Training with Transcranial Direct Current Stimulation'.

78 Reinhart, R. M. G. and Nguyen, J. A., (2019), *Nature Neuroscience*, 'Synchronizing rhythmic brain circuits'.

79 Martiny, K., et al., (2010), *Biological Psychiatry*, 'Transcranial low voltage pulsed electromagnetic fields in patients with treatment-resistant depression'.

80 Further detail can be found at https://www.vmocion.com.

81 Flöel, A., et al., (2008), *Journal of Cognitive Neuroscience*, 'Noninvasive brain stimulation improves language learning'.

nerve cells and technological components or devices.[82] Examples of one-way interfaces are the cochlea implant (hearing aid) or neurofeedback training to enhance visual attention.[83] Implants produced specifically for augmentation are relatively underdeveloped, although there are examples: vagus nerve stimulation has shown itself to act as a memory stimulator.[84] Stimulating the brain by using implanted electrodes during learning has been shown to improve memory capacity by up to 30%.[85]

Rapid advances are being made in the ability to decode brain signals, examples include the recognition of words, correcting robot mistakes and recognising music from electroencephalography.[86] Non-invasive interfaces have also been shown to allow human brain-to-brain communication and problem solving.[87] Experiments using invasive interfaces have demonstrated information transfer and teamwork in connected laboratory animals, as well as limited thought-speech translation.[88]

Potential and issues. Future improvements of brain stimulation may include better ways of targeting brain areas and improved understanding of how it works.[89] Using a combination of stimulations for more complex functions, deeper stimulation and interactive systems that tune themselves to brain activity are also likely to deliver further enhancements.

The direct link between brain and action is an effective alternative to traditional interfaces, especially in a military environment where there is a risk of overloading cognitive and sensory functions. The brain-computer interface detects when certain areas of the brain are cognitively activated (for example, certain thoughts) and transmits this, thus enabling brain-controlled action or communication. Brain-computer interfaces have the potential to enhance human-machine teaming whereas brain-brain interfaces would enhance human to human teaming on the battlefield. With the ascent of artificial intelligence, brain-computer interfaces can also provide new ways of accessing vast amounts of information, and ways of communication. Two-way brain-computer interfaces may enable an even wider set of cognitive augmentation than the purely biological. However, this technology is not expected to be realised within the 2050 time frame.

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82 Forbes,(2019), 'Brain-Computer Interfaces And Mind Control Move One Step Closer To Becoming Reality'.

83 Ordikhani-Seyedlar, M., et al., (2016), *Frontiers in Neuroscience*, 'Neurofeedback therapy for enhancing visual attention: state-of-the-art and challenges'.

84 Clark, K.B., et al., (1999), *Nature Neuroscience*, 'Enhanced recognition memory following vagus nerve stimulation in human subjects'.

85 New Scientist, (2017), 'Brain implant boosts memory'.

86 Kang, T., et al., (2017), *International Workshop on Symbiotic Interaction*, 'Predicting What You Remember from Brain Activity: EEG-Based Decoding of Long-Term Memory Formation'; Salazar-Gomez, A.F., et al., (2017), 2017 IEEE International Conference on Robotics and Automation (ICRA), 'Correcting robot mistakes in real time using eeg signals'; and Schaefer, R. S., et al., (2011), *NeuroImage*, 'Name that tune: decoding music from the listening brain'.

87 Jiang, L., et al., (2019), *Scientific Reports*, 'BrainNet: a multi-person brain-to-brain interface for direct collaboration between brains'.

88 Pais-Vieira, M., et al., (2013), *Scientific Reports*, 'A brain-to-brain interface for real-time sharing of sensorimotor information'.; and Anumanchipalli, G. K., et al., (2019), *Nature*, 'Speech synthesis from neural decoding of spoken sentences'.

89 Fertonani, A. and Miniussi, C., (2017), *The Neuroscientist*, 'Transcranial electrical stimulation: what we know and do not know about mechanisms'.

Sensory augmentation

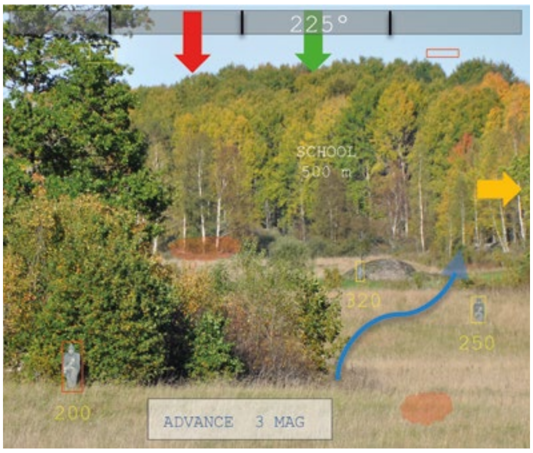


Sensory augmentation aims at extending the sensory range or acuity either by using gadgets/wearables to transduce external information to the human senses (for example, converting infrared light to visible light) or modification of the senses themselves. Gadgets/wearables can be used to transduce external information to the visual, auditory and tactile senses. Vibrations of low magnitude from distant vehicles can be detected by foot-mounted sensors and translated into vibrations in the shoe or 3D audio sound that provides a directional cue. Chemical sensors detecting improvised explosive devices can alert the soldier using any or all of audio, vision, vibration or even olfactory displays. Navigation can be enhanced by a vibro-tactile belt that always indicates the direction of magnetic north.[90]

A multimodal approach using more than one type of display type has the advantage that information can be accessed and absorbed by more than one sensory pathway. The brain extracts patterns of meaningful information from the sensory system, and this creates a combined experience of simultaneous stimuli. Simultaneous presentation may decrease mental workload and increase the chance of recognising important phenomena that would otherwise be missed. With information filtering and enhancement, this has the potential of improving situational awareness while reducing workload and risk of overload.

Another approach is to transduce what is being sensed into a form that can be interpreted by the human senses. Sensory remapping (turning signals into information) is already in use. Due to the ability of the brain to adapt to new types of information (cortical plasticity), a large set of possible inputs may be usable. Methods could include adding new sensors/transducers and connections into the brain, perhaps also in combination with genetic therapy. One example is coating retinal cells with nanoparticles so that light in the infrared spectrum can be seen.[91]

Augmented reality



Augmented reality is a technique for displaying different types of information in the user's field of view. The information is usually projected close to the eye with the help of glasses or helmet visor, but there are experiments to present information in the outside world as a hologram. With augmented reality, the information is presented so that it is geographically correct in real time and symbology is used to highlight important information. Suggested actions, as determined by built-in artificial intelligence

90 Nagel, S. K., et al., (2005), *Journal of Neural Engineering*, 'Beyond sensory substitution — learning the sixth sense'.

91 Nano week, (2019), 'Nanotechnology makes it possible for mice to see in infrared'.

functionality, could aid the user in making decisions. By sharing information from other sources, such as group members, it will be possible to increase battlespace awareness.

Section 3 – Social augmentation, communication and interaction

Social augmentation is designed to deliver improvements to social interaction, including new forms of communication, enhanced team performance, language acquisition as well as improving ethical performance. Methods for making communications faster, clearer, deeper and enabling new forms of communication between individuals, groups and machines are expected. Drugs, user interfaces, software and wearable equipment will all play a role in enabling this.

Substances

Drugs may improve an individual's sense of well-being or enhance emotional resilience. Drugs could also be used to boost group performance, and more concerning, make them more susceptible to various forms of control and manipulation. Drugs might help people learn languages more effectively and quickly.[92] For example, it might be possible to use drugs to 'reopen' the capacity normally found in the very young (the infant critical window) to learn languages rapidly and perfectly.[93] One area that is relatively unexplored is how sociability is learnt. Experiments involving mice have demonstrated that there is a critical period when young mice learn sociability, and that drugs can be used to reopen this learning period.[94]

Human-machine teaming

Human-machine teaming, sometimes called human-autonomy teaming or manned-unmanned teaming, refers to the ability to use advanced mechanised units (such as unmanned aerial vehicles or robots) as a part of a team where the machines take on roles previously performed by people. Communication based on gestures has been proposed for control of partially autonomous robots in the battlefield. Human-machine teaming will have the same dependencies as human-human teams, including cooperation, integration of abilities and knowledge and complementary areas of responsibility. The foundation of a good team builds on communication (knowing how and when to communicate), team coordination (shared mental models, mutual performance monitoring, assistive behaviour and adaptability, and leadership), and cooperation (team orientation and mutual trust).[95]

92 Breitenstein, C., et al., (2004), *Neuropsychopharmacology*, 'D-amphetamine boosts language learning independent of its cardiovascular and motor arousing effects'.

93 Hensch, T. K. and Bilimoria, P. M., (2012), Cerebrum: the Dana forum on brain science 2012, 'Re-opening windows: manipulating critical periods for brain development'.

94 Nardou, R., et al., (2019), *Nature*, 'Oxytocin-dependent reopening of a social reward learning critical period with MDMA'

95 Mosier, K., et al., (2017), *NASA Technical Memorandum*, 'Autonomous, context-sensitive, task management systems and decision support tools I: Human-autonomy teaming fundamentals and state of the art'.

Tele-existence

Tele-existence is a natural progression from augmented reality and virtual reality and gives the user a real time experience of being at another location, with the ability to perform tasks and interact with this remote environment. Tele-existence gives the user the capability to manipulate robots from a distance using a headset and haptic gloves (movements of these gloves controls the movement of the remote device). Telemedicine is paving the way in this field, allowing doctors to diagnose and, in some advanced cases, perform surgical procedures in separate locations to their patients. Defence applications could enable avatars (remote representations of the user) to be used in circumstances too dangerous for people, such as bomb disposal, clearance diving or even activities in space: the activity occurs in the physical environment, but the user stays out of harm´s way.

Tele-existence and virtual reality may further enhance social communication over extended distances and real time artificial intelligence-based translation systems could overcome language and cultural barriers. The Internet of Things and big data is likely to be used to facilitate group communication, for example, by displaying, interpreting and illustrating social networks.

Ethical behaviour

Controversially, it may be possible (and desirable) to morally enhance personnel to prevent malicious activity.[96] Such a process is likely to include methods that enhance moral reflection, self-control and empathy for others. It is a wildcard since while most people may find improved memory or motivation appealing, they typically believe their morals are already fit for purpose.[97] In fact many believe that 'enhancing' their morals will leave them worse off.[98] Artificial intelligence could also be used to enhance ethical decision-making, for example in a military headquarters.[99] Widespread uptake of technology to deliver moral enhancement will depend as much on social acceptance as the development of the technology.

Potential and issues. Linking minds and coordinating groups is likely to be a far more effective way of improving cognition, perception and, perhaps, emotions than improving individual brains. It is plausible that as social neuroscience progresses, we will find interventions that improve social learning and interpersonal skills. Being able to reopen the brain to social learning, normally only available in the developing brain, may have application in therapy, education and adapting to new social circumstances and learning languages.[100]

96 Persson, I. and Savulescu, J., (2008), *Journal of Applied Philosophy*, 'The perils of cognitive enhancement and the urgent imperative to enhance the moral character of humanity'.

97 Riis, J., et al., (2008), *Journal of Consumer Research*, 'Preferences for enhancement pharmaceuticals: The reluctance to enhance fundamental traits'.

98 Zohny, H., (2018), *Medicine, Health Care*, and Philosophy, 'Moral Enhancement and the Good Life'.

99 Giubilini, A. and Savulescu, J., (2018), *Philosophy & Technology*, 'The artificial moral advisor. The "Ideal Observer" meets artificial intelligence'.

100 Blundon, J. A., et al., (2017), *Science*, 'Restoring auditory cortex plasticity in adult mice by restricting thalamic adenosine signalling'.

Section 4 – Omnipotent technologies

Genetic technologies could have application in all areas of human augmentation. For this reason we have classified it, and other technologies with a similarly broad scope of application, as an omnipotent technology.

Genetic engineering



Genetic engineering refers to modification of reproductive cells (germline engineering), or cells in the grown organism (somatic modification). Germline enhancement affects all cells in the organism and the change is heritable (meaning it can be passed on to the next generation). Somatic modification, on the other hand, affects only the target cells and the cells descended directly from them, and thus limited to the individual subjected to the treatment. Somatic modification, or gene therapy, to treat or prevent disease is still experimental although there have been significant improvements in recent years.

Clustered regularly interspaced short palindromic repeats (CRISPR/Cas9) is a technique for cutting specific DNA sequences. The method is based upon precise manipulation of selected gene sequences by switching off, repairing or replacing existing genes with genes engineered to produce a desired enhancement. Lessons from using CRISPR/Cas9 has led to swift progress and in 2019 the technology was used in the treatment of a patient with a deadly genetic disorder.[101]

Potential and issues. Based upon what we know today, and if current predictions are correct, genetic modification has, by far, the greatest potential for human enhancement. According to the United States Defense Advanced Research Projects Agency (DARPA), genetic modification could be used to create super soldiers who 'kill without mercy, do not get tired, do not show fear and behave more like a machine than a human'.[102]

There are, however, concerns regarding the safety of genetic modification, particularly for heritable changes which are considered far more controversial than using the technique to treat an individual when there are no other options available. To enhance general abilities rather than cure diseases, however, the ability to edit DNA is not enough. It is also necessary to understand the epigenetics, the complex mechanisms that govern how the gene manifests itself in the body. Multiple gene activities and various levels of expression are required for more complex capabilities. Genome editing works well where there are single gene mutations resulting in a defined disease, but have a long way to go for multi-genetic disorders.

101 Further detail can be found at https://www.npr.org/2019/07/29/746365947/doctors-in-the-u-s-use-crispr-technique-to-treat-a-genetic-disorder-for-the-1st-.

102 Sawin, C., (2016), *The Journal of High Technology Law*, 'Creating Super Soldiers for Warfare: A Look into the Laws of War'.

Genetic testing and selection

The cost of sequencing a genome has reduced and it has become easier to use the technique to identify predisposition for both undesirable traits, such as certain illnesses, and desirable characteristics, such as muscle density. Genetic testing could be used to screen people for particular tasks – for example, cardiovascular endurance or for propensity to PTSD.[103] It could also be used to identify the best enhancements or other interventions for each individual, as well as identifying their health risks.

Genetics could be used to select embryos for intelligence by 2050. While selection during normal in vitro fertilisation (IVF) is unlikely to have a significant effect, if a process of in vitro iteration (where multiple generations are generated and selected) is used, this could lead to radically more intelligent people emerging.[104] Whether this happens is dependent on many unknowns, including acceptance of the technique and technical feasibility (for example, gaining sufficiently large training datasets of genetics and how intelligence is manifest).

Potential and issues. Whilst genetic testing and selection could play a major role in human enhancement, it is dependent upon significant increases in our understanding of the role genes play in human development, and the role that other factors such as environment and nurture play. The fields of statistics and probability will have an important role to play if the potential of genetic testing and selection are to be realised. Legal and ethical issues will also play a crucial part in deciding whether this technology is accepted by society.

Section 5 – Integrated health strategies

Using technology to optimise training (both physical and mental), sleep, nutrition, hydration and stress management is expected to deliver significant results. The effect and usability is expected to increase when using these technologies together as an integrated effort.

Virtual reality

Virtual reality, a technology which allows the user to be exposed to, and interact with, computer generated (synthetic) environments could have an important role in enhancing performance. For example, the technology could be used to rehearse missions, increasing individual readiness and to prepare people for the stress of operations. Virtual reality could be used to create traumatic events to 'inoculate' people. Similarly, recreations of traumatic events could be used to treat anxiety, hyper-vigilance, PTSD and potentially other mental disorders. Virtual reality could also be used by those on operations to escape the horrors of war, even for brief moments, thus enhancing their mental resilience.

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103 Nievergelt, C. M., et al., (2019), *Nature Communications*, 'International meta-analysis of PTSD genome-wide association studies identifies sex-and ancestry-specific genetic risk loci'.

104 Shulman, C. and Bostrom, N., (2014), Global Policy, 'Embryo Selection for Cognitive Enhancement: Curiosity or Game-changer?'.

Computer-assisted brain training

Computer-assisted brain training has generated significant interest, even though evidence of its effect on cognition in areas other than those being specifically trained remains elusive.[105] Since conventional training can enhance higher cognitive functions (for example, decision-making and reasoning), it should be possible to adapt computer-assisted brain training to enhance general cognition. In the coming decades, blending computer-assisted brain training with conventional training could become highly effective, especially in organisations and groups that have the necessary processes for evaluating and adapting training. Although there is some evidence to suggest that brain training applications improve cognition it is not clear they lead to lasting improvements.[106] Similarly, the benefit of brain training in practical settings and for improving general intelligence has also been questioned.[107]

Personalised training

Personalised training consists of four different aspects: training adaption, nutrition adaption, supplements and recovery. At a biological level, people have different capabilities in each of these four areas and by tailoring activities to an individual's biological limit, optimal results can be achieved. Machine learning could be used to track an individual´s gain in strength (for example, number of repetitions for a given weight) and receive recommendations regarding training routine needed to reach optimal muscle development and the same principles could be applied to personalisation of nutrition. Smartphone applications that use machine learning to generate personalised regimes are already under (commercial) development.

The synergy between training and using augmentation technologies is likely to be significant. For example, technology has helped scientists understand how physical exercise contributes to increased intelligence. In many cases users will need to undertake training to derive the full benefit of augmentations. Similarly, technology can be used to optimise recovery rates both to enhance training effectiveness and promote recovery.

Sleep optimisation

Sleep has positive effects on many processes including mental and physical development, whilst sleep deprivation impairs vigilance and most cognitive functions. Technology can be used to identify an individual's most effective sleep patterns, leading to improvements in performance.

105 Moreau, D. and Conway, A. R., (2013), *International Review of Sport and Exercise Psychology*, 'Cognitive enhancement: a comparative review of computerized and athletic training programs'.

106 Hardy, J. and Scanlon, M., (2009), *Luminosity*, 'The science behind lumosity'; Shute, V. J., et al., (2015), *Computers & Education*, 'The power of play: The effects of Portal 2 and Lumosity on cognitive and noncognitive skills'; Bainbridge, K. and Mayer, R. E., (2018), *Journal of Cognitive Enhancement*, 'Shining the light of research on Lumosity'.

107 Jak, A. J., et al., (2013), *Neuropsychology Review*, 'Crosswords to computers: a critical review of popular approaches to cognitive enhancement'.

Yoga and meditation

Yoga and meditation are based on conscious control over body and mind. Such methods are used to improve mood, tolerance to pain, ability to manage stress, and to reduce anxiety. Similarly, mindfulness and associated breathing techniques can be used to gain focus and reduce distraction. Regular practice of these methods can have positive effects and technology could play a role in identifying the most effective techniques for each individual. These techniques could also have military application, for example, yoga has been shown to improve the quality of sleep in the military population and breathing techniques can improve awareness and decision-making during tactical operations. The use of these techniques by the military though is not without controversy.[108]

Status monitoring

Technology to monitor an individual's physiology is becoming mature and wearable technologies already allow significant quantities of data to be collected. Technology in this area is, however, improving rapidly, and wearables and smart textiles are likely to lead to further improvements in the quantity, quality and precision of data collected. Combining data collection with the ability to analyse and interpret it, for example, by using artificial intelligence, is likely to lead to significant insights into how human performance can be enhanced.



Technology could be used to monitor, in real time, an individual's combat readiness. Their level of sleep deprivation, nutrition and hydration state, to name a few areas, could all be monitored in real time, as could their levels of fitness. Regardless of the application, however, reference data will need to be collected and tools for analysis, including algorithms, will need to be developed if the potential of monitoring technologies is to be realised. Appropriate infrastructure will also need to be developed so that data can be collected and stored efficiently and securely.

Section 6 – Health

Human augmentation is also expected to play a major role in improving health care. For example, by helping to prevent illness, treat injuries and illnesses as they occur, and to support general physical and mental well-being throughout life. Technologies of particular relevance include active prosthesis, accelerated healing, mental health recovery, slowing ageing and age-related impairments, and life extension. Technology will also have a major role in improving the testing and assessment of risk factors including pre-symptomatic and predictive testing.

108 Kreplin, U., et al., (2018), *Scientific Reports*, 'The limited prosocial effects of meditation: A systematic review and meta-analysis'; Joshi, A.V., (2019), *Warrior Pose: Building Readiness through Resilience—Yoga and Meditation in the Military*; Grossman, D. and Christensen, L. W., (2008), *On Combat. The Psychology and Physiology of Deadly Conflict in War and in Peace*.

Preventive measures

Preventative measures improve resilience and provide protection from emerging threats. Human augmentation may allow the immune systems to be tuned so that it increases protection against toxins and pathogens, and, possibly, to prevent immune responses to implants. Technology could also be used to reduce injuries by supporting the development of optimised physical and mental training. For example, as described earlier, immersion in realistic virtual environments may help soldiers prepare for traumatic experiences, preventing PTSD. As we approach 2050, the future soldier could be equipped with an integrated, networked artificial immune system. The system could consist of a wearable platform that would continuously monitor for threats and automatically provide countermeasures, for example, an antidote in response to a toxin or antibiotic or anti-viral in response to an infection.[109]

Synthetic biology

Synthetic biology could be used to rapidly develop new treatments and vaccines. It could also be used for producing biological weapons such as designer viruses and diseases. Designer viruses and diseases could be designed so that they are highly volatile and mutative, making it very difficult to produce effective countermeasures, or extremely personalised to target specific groups of people, possibly even individuals.



Symbiotic organisms such as those that live in the gut have a profound effect on the host's health.[110] It is plausible that genetically engineered organisms could be introduced into the gut to enhance health and/or performance and to treat disease.[111] For example, it is thought that the anti-diabetes drug metformin (which has also been studied for its possible anti-ageing effects) may act through its interaction with the microbes in the human gut.[112]

Precision medicine

Precision medicine is a move away from a 'one size fits all' approach medicine to one that tailors medical interventions to the individual. The field combines pharmacology and genomics in an approach to tailor dosage and medication to individual needs. The collection of biological, and other, big data and continuous monitoring will enable specialised medical support for each Serviceperson and ensure that they are at peak physical condition on the battlefield.

109 Sullivan, I., et al., (2018), Mad Scientist Laboratory, 'Bio Convergence and Soldier 2050 conference'.

110 Bravo, J. A., et al., (2011), *Proceedings of the National Academy of Sciences*, 'Ingestion of Lactobacillus strain regulates emotional behavior and central GABA receptor expression in a mouse via the vagus nerve'.

111 Hillman, J. D., et al., (2000), *Infection and Immunity*, 'Construction and characterization of an effector strain of Streptococcus mutans for replacement therapy of dental caries'.

112 Rodriguez, J., et al., (2018), *Current Opinion in Clinical Nutrition & Metabolic Care*, 'Metformin: old friend, new ways of action–implication of the gut microbiome?'.

Restorative augmentation technologies

Restorative technologies include efforts to replace or upgrade damaged or missing limbs and organs. Bionic limbs, for example, could replace lost limbs and be controlled using brain-to-machine interfaces. Robotic limbs may provide new abilities and a level of performance beyond the biological limit, for example, super strength. New materials can provide surfaces for implants that are compatible with the environment inside the human body allowing devices to be implanted long term.[113] This, in combination with new industrial methods such as additive manufacturing (which allows 3D printing of biocompatible materials), could allow the production of replacement organs, and skin cells printed directly on wounds.[114] In 2013, a United States company launched the first commercially developed eye implant; enhancing visual performance could be the subject of intense interest in the coming years.[115]

Life extension

Life extension is pushed by people's desire to live a long and healthy life. States are also interested in having a healthy population with high human capital and low health care costs. These two drivers are likely to ensure that resources will continue to be focused on finding ways to extend the years of good health. At present, most efforts have been focused on age-related disease rather than ageing itself. Interventions in the time frame of 2050 are most likely to focus on countering the damaging effects of ageing, rather than the causes of ageing.[116] Interventions include replacing joints, improving metabolism, treating and preventing cancer, boosting the immune system and developing senolytic drugs, (drugs that remove aged cells).[117] Methods to reduce genetic damage, and improved mitochondrial function are also likely to be developed. It is probable that many, if not all, of these methods will need to be applied in combination to fully remove the effects of ageing. In addition, artificial devices and organs, stem cells and modified tissues are also being explored for regenerative medicine. Direct genetic interventions against the causes of ageing (a real 'cure') are likely to require a much deeper understanding of biology than we currently have, and probably a redesign of key genetic programs. Life extension is an area of augmentation where significant DIY biology activity is ongoing, often in the form of self-experimentation, which may lead to unexpected developments.

Section 7 – Future potential

There are major gaps in our understanding of how a specific manipulation in one part of the body may have significant consequences elsewhere. The precise effect that can be obtained from existing as well as potential technologies are often unknown or poorly documented. One example is the long chain of events that causes physical exercise

113 Kozai, T. D. Y., et al., (2012), *Nature Materials*, 'Ultrasmall implantable composite microelectrodes with bioactive surfaces for chronic neural interfaces'.

114 Albanna, M., et al., (2019), *Scientific Reports*, 'In Situ Bioprinting of Autologous Skin Cells Accelerates Wound Healing of Extensive Excisional Full-Thickness Wounds'; Shieber, J., (2019), Techcrunch.com, '3d-printing organs moves a few more steps closer to commercialization'.

115 Marcus, G. and Koch, C., (2014), *The Wall Street Journal*, 'The Future of Brain Implants'.

116 López-Otín, C. et al., (2013), *Cell*, 'The hallmarks of aging'.

117 Scudellari, M., (2017), *Nature*, 'To stay young, kill zombie cells'.

to generate cognitive improvement. An understanding of the foundational working mechanisms of both the technology and the human body is necessary for effective and safe augmentation. Thus, research efforts which aim to investigate and document the effects of even well-established substances are warranted. This is particularly important in the context of precision medicine (the optimisation of health measures on an individual basis).

Research in other fields such as artificial intelligence and machine learning, will also have an impact on the development of human augmentation. Whilst there is no evidence (yet) that superhuman cognitive ability can be achieved biomedically, collaboration with artificial intelligence shows promise. The right (brain-computer) interfaces could allow certain mental tasks to be offloaded to computers. For example, numerical calculations and simulations could be triggered by thought and the results made mentally available; although, the effectiveness of such collaboration depends both on the suitability of tasks and how open-ended the system is.



Advancements in four related fields of technology, known collectively as nanotechnology, biology, information technology, and cognitive science (NBIC) are expected to converge, and ultimately unify, leading to radical improvements in human performance through the integration of these technologies. The combination of precision medicine, nutrition, and training could open up entirely new possibilities. For example, in bodybuilding and powerlifting, focus on optimising the training routines are also being matched with nutrition and sleep regimes to achieve the greatest combined effect possible. Effort in these areas is likely to open up possibilities to improve the performance of the group as well as the individual.

The key to developing effective human augmentation is an improved understanding of how both the body and technology work and how they work together. This will require access to, and analysis of, personal data: whether it is psychophysiological variables, collection of personal reference data, analysis of medical markers, or supervision of training routines. Only if these building blocks are put in place, will there be enough understanding to ensure that human augmentations can be made precisely and with certainty that the desired effect will be achieved. Only when (or if) this happens will the science of human augmentation arrive.

Predicting the future is challenging. Initially promising solutions may reach dead ends and attitudes towards new technology will affect rate of acceptance within society. As there are legal, ethical and safety issues to consider during development, the time from initial design to implementation is often long in the field of biotechnology.

Notes

Glossary

Part 1 – Acronyms and abbreviations

3D	three-dimensional
5G	fifth generation
BTWC	Biological and Toxin Weapons Convention
CRISPR	clustered regularly interspaced short palindromic repeats
DARPA	Defense Advanced Research Projects Agency
DCDC	Development, Concepts and Doctrine Centre
DIY	do-it-yourself
DNA	deoxyribonucleic acid
DOTMLPF	doctrine, organisation, training, materiel, leadership and education, personnel, and facilities
EPO	erythropoietin
GDPR	General Data Protection Regulation
GPS	Global Positioning System
HIV	human immunodeficiency virus
ISTAR	intelligence, surveillance, target acquisition and reconnaissance
IVF	in vitro fertilisation
JCN	joint concept note
LED	light emitting diode
LSD	lysergic acid diethylamide
MDMA	methylenedioxymethamphetamine
MOD	Ministry of Defence
NBIC	nanotechnology, biotechnology, information technology and cognitive science
PTSD	post-traumatic stress disorder
RAHS	risk assessment and horizon scanning
SWOT	strengths, weaknesses, opportunities and threats
UK	United Kingdom

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